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The Journal of

THE ROYAL AERONAUTICAL SOCIETY

CONTENTS DECEMBER 1948

SOME ASPECTS OF POWER PLANT DEVELOPMENT
DR. E. W. STILL, B.SC., A.C.G.I., F.R.AE.S., A.M.I.MECH.E.

DELAYS IN LANDING OF AIR TRAFFIC
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CORRESPONDENCE

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"It's easier to do business with a man than an address!"

Sydney last month, Johannesburg last week . . . New York next week! As my firm's export manager, I find it pays to do business with a man and not just an address. Correspondence is cut to the bone, misunderstandings are prevented, problems are discussed and solved right on the spot.

That's where Speedbird service and B.O.A.C.'s more than 72,000 miles of world-wide air routes come in. B.O.A.C. usually flies where I want to go, and Speedbird service gets me or my freight there in a hurry and right on schedule. Arranging my trips is easy. The local B.O.A.C. Appointed Agent fixes everything. No crowds or confusion, and no red tape. Everything goes like clockwork, but with this important difference: there's the *personal* touch!

About the actual flight . . . It's good, *really* good — from beginning to end. If you're hungry, you can eat wonderful food — " on the house " too. If you're tired, the comfortable seats practically lull you to sleep. Everything — and I mean *everything* — reflects B.O.A.C.'s 29-year-old tradition of Speedbird service and experience.

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THE ROYAL AERONAUTICAL SOCIETY
4 HAMILTON PLACE, PICCADILLY, LONDON, W.1

DECEMBER NOTICES 1948

JOURNAL PREMIUM AWARDS

The Council have set aside an annual sum of £250 for the award of premiums for papers published in the *Journal* and the Council hope that members (or non-members) will contribute papers on their own special subjects.

CHRISTMAS HOLIDAYS

The Offices and Library of the Society will be closed from Friday, 24th December, until Wednesday, 29th December, at 9 a.m.

CONTENTS OF THE DECEMBER JOURNAL

Some Aspects of Power Plant Development, by Dr. E. W. Still, B.Sc., A.C.G.I., F.R.Ae.S., A.M.I.Mech.E.
Delays in Landing of Air Traffic, by T. Pearcey, A.R.C.S.
Correspondence.
Reviews.
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BLERIOT LECTURE

The Second Bleriot Lecture will be given on 10th February 1949 before the Royal Aeronautical Society, by Mons. Brocard, Ingénieur en Chef à la Société des Ateliers d'Aviation, and Mons. Hussenot, Ingénieur en Chef de l'Aéronautique, Chef du Service des Méthodes au Centre d'Essais en vol de Brétigny, Président de la Commission d'Aérodynamique de Vol de l'A.F.I.T.A.

The subject of the Lecture, which will be delivered in English by Mons. Brocard, will be French Experimental Methods of Perfecting the Aerodynamic Properties of Prototypes in the Project Stage for the Purpose of Flight Tests.

It will be recalled that the Bleriot Lecture will be delivered alternately in Paris and London under the auspices of the Association Française des Ingénieurs et Techniciens de l'Aéronautique and the Royal Aeronautical Society. The first lecture was delivered in Paris on 12th May 1948 by Air Commodore F. R. Banks, Fellow of the Society.

CITY AND GUILDS OF LONDON INSTITUTE

For many years the City and Guilds of London Institute, Department of Technology, has provided examinations on Aeronautical Engineering Practice.

The whole of these examinations have recently been revised by a Committee on which the Society is represented by Sir Roy Fedden, F.R.Ae.S., and Professor R. L. Lickley, F.R.Ae.S., and of which Sir Roy Fedden is Chairman.

The aim of these examinations has been to give the young mechanic a really sound grounding in the technical aspects of aeronautical engineering. The scheme of syllabuses and examinations has been drawn up to meet the needs of engineering craft apprentices and craftsmen in the Aeronautical Industry. The scheme has been formed with the object of supplementing the student's industrial experience and so improving his skill and understanding as a craftsman.

It is expected that the courses of training provided under the scheme will be arranged and conducted by Technical Colleges in co-operation with local industry.

ANGLO-AMERICAN AERONAUTICAL CONFERENCE 1949

Arrangements are now being completed for the Aeronautical Conference to be held in 1949.

The Conference will spread over five days and will be followed by a number of visits to aircraft firms and to Langley Field and elsewhere.

This second Conference of the two Societies will have read before it some twenty papers covering a wide range of technical activity, and it is hoped that a good British representation will be possible in addition to those who have accepted the Council's invitation to lecture. The Council feel that the opportunity given by these Conferences to make the personal acquaintance of " opposite numbers " on each side of the Atlantic is one which should be taken every advantage of, as such personal contacts will prove of increasing benefit to aeronautical engineers both in this country and the U.S.A.

Members who propose to attend the Conference should inform the Secretary as quickly as possible in order that the necessary arrangements may be made.

COMMONWEALTH FUND FELLOWSHIPS

Applications for the Commonwealth Fund Fellowships for 1949 must be received by the Secretary to the Committee of Award by 1st February 1949.

The Fellowships are awarded by the Commonwealth Fund of New York and are tenable for twelve months in the United States.

There are three categories of Fellowship:—

(1) Ordinary Fellowships.—Open to British Subjects more than 23 and less than 35 years of age on 1st September 1949 who have not worked or studied in any educational or research institution in the United States for one or more academic years. Candidates domiciled in the United Kingdom must be graduates of a recognised university therein. Candidates not domiciled in the United Kingdom must be graduates of a recognised University in Australia, New Zealand or South Africa, and must have studied at, although not necessarily graduated from, a University in the United Kingdom.

Twenty Ordinary Fellowships will be offered in 1949.

(2) Home Civil Service Fellowships.—Open to candidates holding permanent appointments in the higher ranks of the Civil Service in Great Britain. Three of these Fellowships will be offered in 1949.

(3) Overseas Civil Service Fellowships.—Open to candidates who hold appointments overseas under the British Government, or the Governments of Australia, New Zealand, or South Africa, or the Government of British Colonies, Protectorates, or trust territories.

Five of these Fellowships will be offered in 1949.

All categories of Fellowships are now open to women.

Full particulars and application forms may be obtained from The Secretary, Commonwealth Fund Fellowships, 35 Portman Square, London, W.1.

HELICOPTER ASSOCIATION JOURNAL

Members of the Society who would be interested to receive the Journal of the Helicopter Association are asked to inform the Secretary of the Royal Aeronautical Society. If enough applications are received a reduction in the price of the Helicopter Association Journal will be made to them.

R.F.C., R.N.A.S. REUNION

A Reunion for R.F.C. and R.N.A.S. personnel is being organised and it is hoped to hold it early in January 1949 at Londonderry House.

Will any member of the Society who is interested write to Geoffrey Dorman, Sponson Developments Ltd., 3 Albemarle Street, Piccadilly, London, W.1?

MEMBERS' NEW APPOINTMENTS

L. G. Frise, B.Sc., Fellow—Chief Engineer, Percival Aircraft Ltd.

F. A. Kerry, B.Sc., Associate Fellow—Assistant Chief Designer, Saunders-Roe Ltd.

J. A. C. Manson, B.Sc., Fellow—Personal Assistant to the General Manager, Fairey Aviation Company Ltd.

LECTURE PROGRAMME—1948-1949

Unless otherwise stated, lectures will be held at 6 p.m. in the Lecture Hall of the Institution of Civil Engineers, Great George Street, London, S.W.1 (by permission of the Council of the Institution). Tea will be served at 5.30 p.m.

Thursday, 16th December 1948
Present Thoughts on the Use of Power Flying Controls in Aircraft, by D. J. Lyons.

Thursday, 13th January 1949—The Auto-Pilot, by F. W. Meredith, B.A., F.R.Ae.S.

Thursday, 27th January 1949—Title and Author to be announced.

Thursday, 10th February 1949—The Second Louis Bleriot Lecture, to be read by M. Brocard and M. Hussenot.

Thursday, 24th February 1949—Flutter and Stability, by Professor W. J. Duncan, D.Sc., M.I.Mech.E., F.R.Ae.S., F.R.S.

The Lecture Card will be issued with the January 1949 Journal.

GRADUATES' AND STUDENTS' SECTION—LECTURES

Tuesday, 7th December 1948—Papers read by members of the Graduates' and Students' Section.

Tuesday, 21st December 1948—Production, The Dynamics of People at Work, by J. V. Connolly, B.E., A.F.R.Ae.S., Professor of Aircraft Economics and Production at the College of Aeronautics.

Meetings will be held in the Library of the Royal Aeronautical Society, 4 Hamilton Place, W.1, at 7.30 p.m. *The Library will not be open before 7 p.m.*

BELFAST BRANCH

Tuesday, 7th December 1948—The Weight Aspect in Aircraft Design, by L. W. Rosenthal, A.F.R.Ae.S.

Tuesday, 14th December 1948—Evening of Films.

Tuesday, 11th January 1949—One Thousand Miles an Hour, by Professor G. T. R. Hill, M.C., M.Sc., F.R.Ae.S., M.I.Mech.E.

Tuesday, 1st February 1949—The Propeller-Turbine Aero-Engine, by F. M. Owner, M.Sc., F.R.Ae.S., M.S.A.E.

Tuesday, 22nd February 1949—Three Lecturettes, by Branch Members, followed by an informal discussion.

Tuesday, 8th March 1949—A Lecture, by P. G. Masefield, M.A., F.R.Ae.S., M.I.Ae.S., G.I.Mech.E. (Title to be announced later.)

Friday, 8th April 1949—General Meeting.

Lectures will be held in the Central Hall, College of Technology, Belfast, at 7 p.m.

BROUGH BRANCH

Wednesday, 15th December 1948—Film Show: The Bell Helicopter, with a commentary by Capt. Youell. *At Hull.*

Wednesday, 19th January 1949—Lecturette Programme, by Members of the Brough Branch. *At Brough.*

Wednesday, 16th February 1949—Jet Engines, by W. T. Winter, The de Havilland Engine Co. Ltd. *At Hull.*

Wednesday, 16th March 1949—Aerodynamics, by J. R. Ewans, B.A. Ltd., Aerodynamics Staff. *At Brough.*

Wednesday, 13th April 1949—The Brabazon Aircraft, by F. H. Pollicut, Bristol Aeroplane Co. Ltd. *At Hull.*

Lectures at *Brough* are held at the Flying Club, at 5.45 p.m.

Lectures at *Hull* are held in the Lecture Hall, Electricity Showrooms, Ferensway, at 7.30 p.m.

COVENTRY BRANCH

Thursday, 9th December 1948—Lecture, by E. Smith, Research Department, Firth-Vickers Ltd.

Thursday, 20th January 1949—Development of the Mamba Engine, by W. H. Lindsey, Armstrong Siddeley Motors Ltd.

Thursday, 17th February 1949—The London-Sydney Air Route, by C. H. Jackson, B.O.A.C.

Thursday, 17th March 1949—The Automatic Pilot, by A. I. O. Davies, Smiths' Aircraft Instruments Ltd.

Thursday, 28th April 1949—Annual General Meeting and Film.

All lectures will be held in the Old Gulson Library, Coventry, at 7.30 p.m.

GLOUCESTER AND CHELTENHAM BRANCH

Wednesday, 15th December 1948—Stiffness and Strength, by Professor A. R. Collar, M.A., D.Sc., F.R.Ae.S. *At Cheltenham.*

Thursday, 20th January 1949—Weather Forecasting in Aviation, by B. C. V. Oddie, B.Sc., Senior Meteorological Officer, R.A.F. Eastern Avenue, Barnwood. *At Gloucester.*

Wednesday, 16th February 1949—The Design of an Aeroplane, by Professor R. L. Lickley, B.Sc., D.I.C., F.R.Ae.S. *At Cheltenham.*

Thursday, 3rd March 1949—Electrical Aircraft Instruments, by E. B. Moss, B.Sc., F.Inst.P., M.I.Mech.E. *At Gloucester.*

Wednesday, 30th March 1949—Radar Aids in Aeronautics, by Dr. S. F. Evans, M.Sc., Ph.D. *At Cheltenham.*

Thursday, 21st April 1949—Annual General Meeting. Followed by Film, Atomic Physics. *At Gloucester.*

All meetings are held at 7.30 p.m. unless otherwise notified.

Gloucester Meetings (Thursdays) are held in the Wheatstone Hall, City Library, Brunswick Road. *Cheltenham Meetings* (Wednesdays) in the Chemistry Lecture Theatre, Grammar School (entrance off Oxford Passage).

HATFIELD BRANCH

Wednesday, 12th January 1949—Blind Landing Technique, by J. W. F. Mercer, B.Sc., A.C.G.I.

Wednesday, 16th February 1949—The Probable Role and Influence of Aircraft in Future Warfare, by Air Marshal Sir Robert Saundby, K.B.E., C.B., M.C., D.F.C., A.F.C.

Wednesday, 16th March 1949—Annual General Meeting.

All meetings will be held at 6.15 p.m. in the de Havilland Senior Staff Mess.

ISLE OF WIGHT BRANCH

Thursday, 16th December 1948—Annual General Meeting and Film Show.

Thursday, 20th January 1949—Aircraft Design from the Airline Point of View, by C. Dykes, M.A., M.Sc., M.S.Ae., M.I.Ae.S.

Thursday, 3rd February 1949—The Probable Role and Influence of Aircraft in Future Warfare, by Air Marshal Sir Robert Saundby, K.B.E., C.B., M.C., D.F.C., A.F.C.

Thursday, 24th February 1949—Naval Aircraft, by Lieut. Commander E. M. Brown, O.B.E., D.F.C., M.A., A.F.R.Ae.S.

Thursday, 10th March 1949—A Lecture, by N. E. Rowe, C.B.E., D.I.C., B.Sc., F.R.Ae.S. (Provisional.)

Thursday, 24th March 1949—Brains Trust.

Meetings will be held in the Sports and Social Club, Saunders-Roe Ltd., East Cowes, Isle of Wight, at 6 p.m.

LEICESTER BRANCH

Wednesday, 8th December 1948—Discussion on Light Aero-Engines. Led by Messrs. J. Gadd, E. Mitchell and W. B. Mathison of Blackburn Aircraft Ltd. (Engine Department).

Wednesday, 12th January 1949—Bird Flight and the Aeroplane, by Captain J. L. Pritchard, Secretary, Royal Aeronautical Society.

Wednesday, 9th February 1949—Airscrews, by E. Danvers, Rotol Ltd.

Wednesday, 9th March, 1949—Charter Flying, by Squadron Leader Wright, Wright Aviation Ltd.

Wednesday, 23rd March 1949—Films.

Wednesday, 13th April 1949—Annual General Meeting and Members' Papers.

Meetings will be held in Room 104, College of Technology, The Newarkes, Leicester, at 7.15 p.m.

LUTON BRANCH

Friday, 7th January 1949—The Light Aeroplane and the Future of Private Flying, by P. G. Masefield.

At the George Hotel, Luton, at 7.30 p.m.

MANCHESTER BRANCH

Wednesday, 15th December 1948—Lightning, by Dr. F. R. Perry, M.Sc.(Tech.), M.I.E.E.

Thursday, 27th January 1949—Flight Testing of Civil Aircraft, by P. A. Hufton, M.Sc.

Thursday, 24th February 1949—The Development of the Mamba Engine, by A. S. Lindsey, M.A., A.F.R.Ae.S.

Thursday, 17th March 1949—Personal Experiences of Early Aerodynamic Research, by Professor Sir B. Melvill Jones, C.B.E., A.F.C., F.R.S., Hon.F.I.Ae.S., F.R.Ae.S.

Thursday, 28th April 1949—Rocket Propulsion and Interplanetary Flight, by A. V. Cleaver, A.R.Ae.S.

All lectures will be held in the Reynolds Hall at the College of Technology, Manchester, at 7.30 p.m.

PORTSMOUTH BRANCH

Friday, 17th December 1948—Some Aspects of Carrier Operation, by Capt. (E.) B. H. Cronk, D.S.C., R.N. (Retd.)

Friday, 14th January 1949—Rocket Propulsion, by A. V. Cleaver, A.R.Ae.S.

Friday, 11th February 1949—Short papers by members of the Branch.

Friday, 11th March 1949—The " Debunking " of Aeronautical Sciences, by C. G. Grey, F.M.R.Ae.S.

All lectures will be held in the Lecture Hall at the Central Library, Guildhall Square, Portsmouth, at 7 p.m.

SOUTHAMPTON BRANCH

Wednesday, 8th December 1948—Rocket Propulsion and Interplanetary Flight, by A. V. Cleaver, A.R.Ae.S.

Wednesday, 12th January 1949—Gliding, by A. H. Yates, B.Sc., A.F.R.Ae.S.

Wednesday, 9th February 1949—Radio Aids, by F. R. Wills.

Tuesday, 8th March 1949—A Lecture, by A. G. Pugsley, O.B.E., D.S.C.

The lectures will be held in the Physics Lecture Theatre, University College, Southampton, at 7 p.m.

WEYBRIDGE BRANCH

Wednesday, 15th December 1948—Annual General Meeting, followed by films of Vickers Aircraft.

Friday, 28th January 1949—Annual Dance, Oatlands Park Hotel.

Wednesday, 9th February 1949—Civil Air Transport, by P. G. Masefield, M.A., F.R.Ae.S., M.I.Ae.S., G.I.Mech.E., Ministry of Civil Aviation.

Wednesday, 9th March 1949—Air Force Requirements and their Origins, by Air Commodore G. W. Tuttle, C.B., C.B.E., D.F.C., Director of Operational Requirements.

Wednesday, 30th March 1949—Junior Prize Lecture, by a Branch Member.

Wednesday, 27th April 1949—Present-Day Problems in Safety Requirements, by W. Tye, O.B.E., B.Sc., F.R.Ae.S., Air Registration Board.

Wednesday, 18th May 1949—Historical Review of Aircraft Development, by Sir Frederick Handley Page, C.B.E., F.R.Ae.S.

Meetings will be held at Vickers-Armstrongs Ltd., Weybridge Works, at 6 p.m., unless previous notice is given.

LAPEL BADGES

Small lapel badges of the Society's crest in metal silver-plated, and in light and dark blue enamel, will be available shortly for members. The cost of each badge will be 3/6 (including postage).

ASSISTANT EXPERIMENTAL OFFICERS

Applications for several appointments as Assistant Experimental Officers to assist with performance testing of aircraft at a Ministry of Supply Establishment in Wiltshire are invited by the Ministry of Supply. Minimum qualification required is Higher School Certificate with mathematics as a principal subject, or equivalent (a National Certificate could be accepted). Candidates with a bias towards physics or engineering and with aeronautical interests are preferred; possession of A.F.R.Ae.S. is an advantage. Opportunities to compete for established posts may occur later.

Inclusive salary range £220-£460 per annum. Rates for women are somewhat lower.

Write quoting A.393/48/A to the Ministry of Labour and National Service, Technical and Scientific Register (K), York House, Kingsway, London, W.C.2, for application forms, which must be returned completed by 30th December 1948.

JOURNAL BINDING

The new prices of binding of Journals will be as follows:—

1948 Volume	14s. 6d.	(including packing and postage)
Previous Volumes ..	16s. 0d.	,, ,, ,, ,,
Cases for 1948 Volume	6s. 0d.	,, ,, ,, ,,

Journals should be sent direct to the Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the Offices of the Society.

Requests for cases, with remittances, should be sent to the Secretary at the Offices of the Society.

CHANGES OF ADDRESS

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).

Grade of membership.

New address (in block letters).

Old address.

Changes of address must be received *before the 15th of the month* in order to be effective for the Journal for the following month.

NEW MEMBERS

Associate Fellows

Frank Andrews, Robert Angles (from Graduate), Alfred William Ballinger, Arthur Lionel Benns (from Graduate), Richard Peter Boswell (from Student), Douglas Thornton Brown (from Graduate), Sidney Riley Brown, Francis Frederick Chamberlain, John Charles Digby Cotes (from Graduate), Kenneth William Course (from Associate), David George Creamer, Brinley Daniel Davies, Frank Frodin (from Graduate), Alfred Louis Fussell, Michael Alec Garnett (from Graduate), Arnold Roydon Bennett Gay, Harry Fenner Glover, Neville Thomas William Harper, Richard George Harvey (from Graduate), Douglas William Holder (from Graduate), Brian Joseph Howison (from Graduate), Robert Guy Huggett (from Graduate), Jules Louis Albert Jarry, Ronald Francis Jelly, Adrian Albert Lombard, Neville Lloyd Lupton (from Associate), David Leonard Marples, William Charles Mongar (from Graduate), Stanley Thomas Moore (from Associate), Stanley Patrick Osborne, Alfred Charles William Rattle (from Graduate), John Howard Rea, Kopula Rama Reddy, Kenneth Edgar William Ridler, Eric William Robson, Hermann Schoenen (from Associate), Roger Hugh Spikes (from Graduate), Edward Egan Storm, Derrick Laird Taylor, Trevor Harry Thornton (from Graduate), John Walmsley, John Henry Walmsley (from Associate), Basil Laycock Walsh, Norman Stanley Watson.

Associates

John Greenwood Alderson, Frank Cutts-Watson (from Student), Ronald Mackinnon Denny, Thomas George Goode, Peter Hadfield, Paul Albert Hartman, Arthur Bertram Roy Hudson, Norman George Huett, Harry McPherson Johnston (from Student), Hubert Samarasinghe Kaviratne, Kenneth Riley Firth Kenworthy, Robert Kenyon, Archibald Norman Kingwill, Ernest Sidney Larkin, John Alfred William Long, Thomas Beattie McClure, Leslie Martin, Douglas Stirling Maxwell, Wilfred Thomas Morgan (ex-Associate), Dudley Cyril Morris, Robert Cox Munro, John Charles Occo, Douglas Seymour Parnacott, John Charles Parry-Jones, Theodore Stanley Revell, John Alfred Ross, Boris Peter Slusarev, Geoffrey Ward Stallibrass, Edwin Arthur Stevenson, Douglas Reginald Pemberton Tipler, Charles Leonard Trevithick, Edward Henry Victor Windsor, Michael Sewell Wooding.

Graduates

Gordon Leyland Anderton (from Student), Frederick Edward Baker (from Student), Edward George Underwood Band (from Student), Anthony John Blaxill (from Student), Raymond Montrose Brown (from Student), Andrew Liddell Buchan (from Student), Harry Charles Channon, Harry Derrick, Graham Norman Galton, Hugh Graham Gillespie (from Student), Thomas Cyril Greaves (from Student), Robert David Mauleverer Harper, Norman Herbert (from Student), Gordon Stephen Frederick Holman (from Student), Peter Bertram Hoskin, Donald Howard (from Student), Philip Jarvis Johnson (from Student), John Arthur Charles Kentwell, Denis Lawrence Lofts (from Student), Donald Lewis Matthews (from Student), Derek Paul Morriss (from Student), Michael John Neale, Keith Jones Oldham (from Student), John Osborn (from Student), Ralph James Pitt, Charles Peter Seward Popkin (from Student), Robert John Rockliff (from Student), John Denman Sibley (from Student), Ronald Montague Silverblatt (from Student), Brian Spencer Soan (from Student), James Wasley Tootell, Ronald Thomas Turner (from Student), Ronald Charles Wakeford (from Student).

Students

Josef Aretz, Derek Bollworthy, Alan Edward Brock, Bryan Robert Alexander Burns, Derek Eaves, Douglas Bryon Garland, William John Harbottle, Janet Patricia Harris, Robert John Hayter, Lancelot John Hope, John Whalley Jellicoe, Frederick Claude Kinchela, Eckart Lemberg, Stuart Gordon Lennox, Laurence Arthur Piper, James Stanford Plowman, Brian Edward Rayner, Stuart Raymond Sarrailhe, Harold George Sevier, Peter John Sheath, David Harry Smith, Victor Frederic Thompson.

Companions

Ali Zubeyir Demirguc, Eugenio Horacio Zucal.

ACKNOWLEDGMENTS

The Council wish to place on record their grateful thanks to Sir Oliver Simmonds for the magnificent collection of lantern slides which he has presented to the Society.

The Council also acknowledge with grateful thanks copies of " Aircraft Engines of the World " 1941 and 1944 from P. H. Wilkinson, Esq.; sets of bound volumes of foreign periodicals from the Ministry of Supply and the National Physical Laboratory Libraries; and back numbers of the Journal from Major B. W. Shilson, Fellow, C. M. Barter, Associate Fellow, and D. D. Jones, Associate.

ADDITIONS TO THE LIBRARY

Pamphlets in italics with location reference following in brackets. Books marked * or ** may not be taken out on loan.

C.c.65—Balloons. C. H. Gibbs-Smith. Penguin. 1948.

D.c.117—Northolt Airport. Ministry of Civil Aviation. H.M.S.O. 1948.

D.c.118—London Airport Ministry of Civil Aviation. H.M.S.O. 1948.

EE.b.94—Aircraft Engines of the World 1941. P. H. Wilkinson. 1941.

EE.b.95—Aircraft Engines of the World 1944. P. H. Wilkinson. 1944.

EE.b.96—Aircraft Engines. R. H. Drake. Macmillan. 1948.

EE.h.39—Steam Turbine Theory and Practice. W. J. Kearton. 5th Edition. Pitman. 1948.

G.c.A.118—The Strength of Light Alloy Struts. J. F. Baker and J. W. Broderick. Aluminium Development Association. 1948.

I.c.38—Vectorial Mechanics. E. A. Milne. Methuen. 1948.

K.c.34—Rockets, Guns and Targets. J. E. Burchard (Editor). Little, Brown & Co., Boston. 1948.

L.d.123—*Notices to Airmen. Nos.* 365-381 inclusive; 383-390 inclusive.

N.a.93—Applied Physics: Electrons, Optics and Metallurgy. C. G. Suits, G. R. Harrison and L. Jordan (Editors). Little, Brown & Co., Boston. 1948.

N.a.94—Measurement of Stress and Strain in Solids. Institute of Physics. 1948.

S.b.154—The Desert Air Force. Roderic Owen. Hutchinson. 1948.

*X.c.B.33—Atomic Energy: Glossary of Technical Terms. U.N.O. 1948.

*X.e.78—Bristol Engineering Directory 1948.
Bristol Engineering Manufacturers' Association Ltd. 1948.

N.A.C.A. Technical Reports

765—*Exhaust-stack nozzle area and shape for individual cylinder exhaust-gas jet-propulsion system. B. Pinkel, L. R. Turner, F. Voss and L. V. Humble.*

780—*Compressible potential flow with circulation about a circular cylinder. M. A. Heaslet.*

781—*Wind-tunnel procedure for determination of critical stability and control characteristics of airplanes. J. H. Goett, P. J. Jackson and S. E. Belsley.*

782—*Wall interference in a two-dimensional-flow wind tunnel, with consideration of the effect of compressibility. H. J. Allen and W. G. Vincenti.*

783—*Compressibility and heating effects on pressure loss and cooling of a baffled cylinder barrel. A. W. Goldstein and H. H. Ellerbrock, Jr.*

804—*Air-consumption parameters for automatic mixture control of aircraft engines. S. J. Shames.*

805—*An analysis of life expectancy of airplane wings in normal cruising flight. A. A. Putnam.*

806—*An investigation of backflow phenomenon in centrifugal compressors. W. A. Benser and J. J. Moses.*

807—*A method of analysis of V-G records from transport operations. A. M. Peiser and M. Wilkerson.*

809—*Principles of moment distribution applied to stability of structures composed of bars or plates. E. E. Lundquist, E. Z. Stowell and E. H. Schuette.*

810—*Analysis and modification of theory for impact of seaplanes on water. W. L. Mayo.*

811—*Preignition-limited performance of several fuels. D. W. Male and J. C. Evvard.*

812—*Knock-limited performance of several internal coolants. D. R. Bellman and J. C. Evvard.*

813—*Correlation of exhaust-valve temperatures with engine operating conditions and valve design in an air-cooled cylinder. M. A. Zipkin and J. C. Sanders.*

814—*A general representation for axial-flow fans and turbines. W. Perl and M. Tucker.*

815—*Method for matching performance of compressor systems with that of aircraft power sections. R. O. Bullock, R. C. Keetch and J. J. Moses.*

817—*Nitrided-steel piston rings for engines of high specific power. J. H. Collins, E. E. Bisson and R. S. Schmiedlin.*

818—*An experimental investigation of rectangular exhaust-gas ejectors applicable for engine cooling. E. J. Manganiello and D. Bogatsky.*

819—*Formulæ for propellers in yaw and charts for the side-force derivatives. H. S. Ribner.*

821—*Effect of NACA injection impeller on mixture distribution of double-row radial aircraft engine. F. E. Marble, W. E. Ritter and M. A. Miller.*

822—*Calculations of economy of 18-cylinder radial aircraft engine with exhaust-gas turbine geared to the crankshaft. R. W. Hannum and R. M. Zimmerman.*

N.A.C.A. Technical Notes

1279—*The determination of elastic stresses in gas-turbine disks. S. S. Manson.*

1452—*An investigation on aircraft heaters. XXVIII—Equations for steady-state temperature distribution caused by thermal sources in flat plates applied to calculation of thermocouple errors, heat-meter corrections, and heat transfer by pin-fin plates. L. M. K. Boelter, E. F. Romie, A. G. Guibert and M. A. Miller.*

1502—*Bearing tests of 14S-sheet and plate. R. L. Moore.*

1514—*Fatigue of gusseted joints. H. H. Langdon and B. Freid.*

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N.A.C.A. Technical Memoranda

1193—*Measurements on compressor-blade lattices. F. Weinig and B. Eckert.*

The following reports have also been received:—

Nationaal Luchtvaartlaboratorium, Amsterdam
Reports S.337, S.341 and F.34.

NOTICES

College of Aeronautics, Cranfield
Reports Nos. 18, 19, 21 and 22.

Australian Council for Aeronautics
Reports Nos. ACA 35, 36 *and* 37.

Publication Scientifiques et Techniques du Ministere de l'Air
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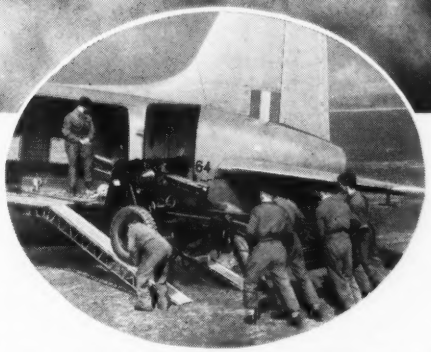

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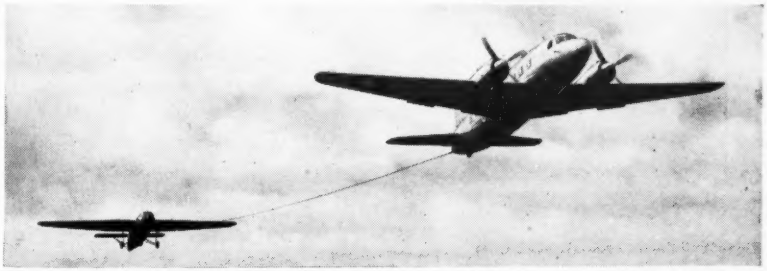

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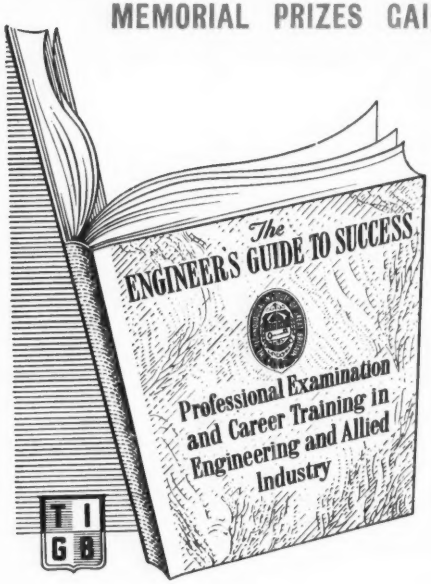

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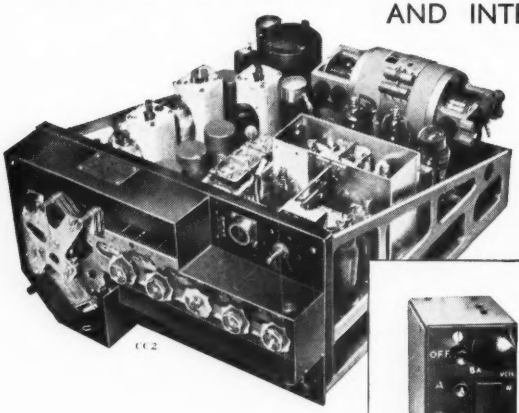

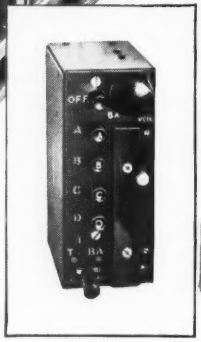

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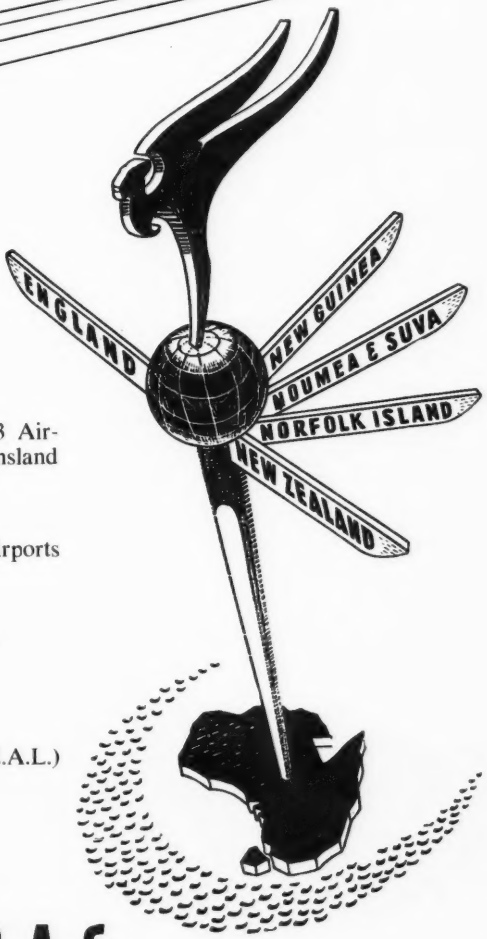

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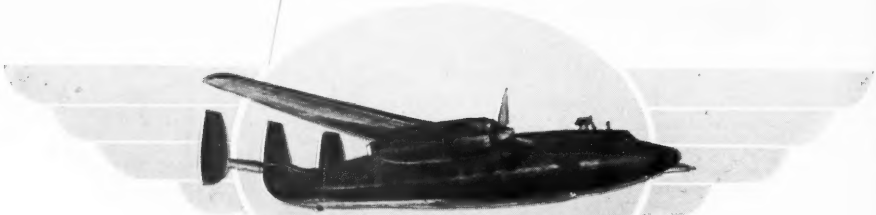

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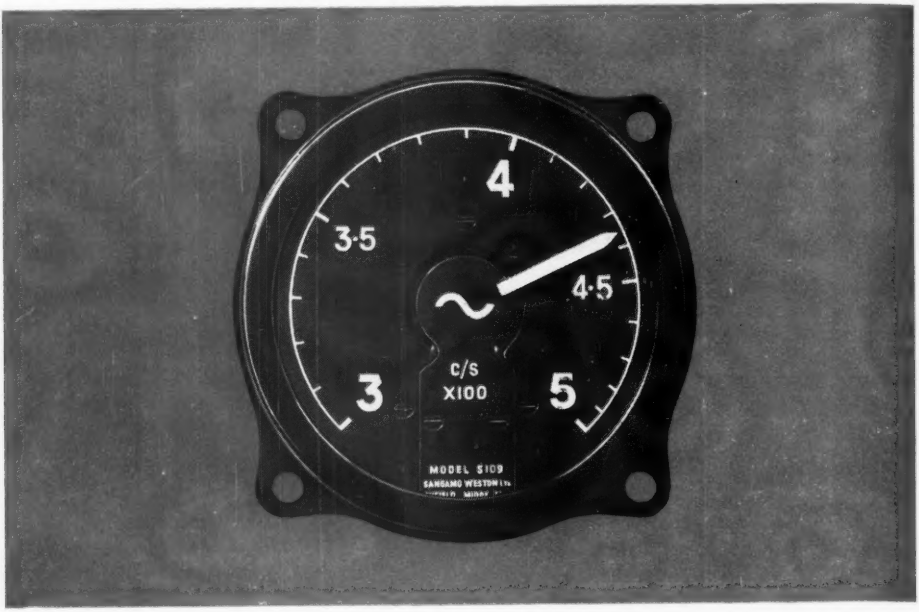

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SOME ASPECTS OF POWER PLANT DEVELOPMENT*

by

Dr. E. W. STILL. B.Sc., A.C.G.I., F.R.Ae.S., A.M.I.Mech.E.

A MAIN lecture of the Society was held at a Branch Centre for the first time on Wednesday, 6th October 1948 when a paper entitled "Some Aspects of Power Plant Development" was given by Dr. E. W. Still, B.Sc., A.C.G.I., F.R.Ae.S., A.M.I.Mech.E., at the Chamber of Commerce, Birmingham, at 7.30 p.m. The Chair was taken by the President of the Society, Dr. H. Roxbee Cox, D.I.C., B.Sc., F.R.Ae.S., F.I.Ae.S.

Dr. H. Roxbee Cox: It had been the custom for the Headquarters in London to arrange a series of lectures every season and the Branches had done similarly in each of their areas. It seemed to the Council of the Society that the time had come to try to bring together even more closely the work of the Branches and the Headquarters. There had been for a long time past a close and good liaison between them, but never quite so close as they would like, and the Council wished to take some special steps to diffuse the effort of the Society over the whole country. One idea that appealed to the Council was to hold some of the principal lectures outside London and this was the first of that kind.

Birmingham was a place which had been first in a good many things, a matter in which he took special pride, for he was born and grew up there. Therefore, it was particularly pleasant for him that the first lecture of the main programme of the Society to be held outside London was being held in Birmingham.

The Society was growing in strength, growing in importance and growing in influence. It was rather surprising that three years after the end of the war the membership of the Society should still be increasing and increasing quite remarkably. Also, the work that it was doing, he thought, was of increasing merit. Part of its work was the spreading of knowledge by means of lectures, and this evening they were to have a lecture which was of a specially interesting and useful kind.

The lecturer, well known to a great many of them, was Dr. E. W. Still from Rolls-Royce Ltd. He had taken his degree in engineering at the Imperial College and had had a varied experience in a number of different engineering organisations. At present he was one of the leading engineers of Rolls-Royce Ltd., exercising his talent at Hucknall. Dr. Still was particularly well qualified to speak on the subject he had chosen this evening because it dealt with power plant development, which had been his particular interest for some years past.

He would ask Dr. Still to give his paper.

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* The 751st Lecture to be read before the Society.

INTRODUCTION.

TRAVELLERS by air to-day only too often can be heard to remark how good it is to be on the ground again. Even now flying is considered by many as an adventure and only those living near an airfield realise the regularity and reliability of air transport.

It is with the hope of removing this feeling of adventure and instilling a sense of security in air travel that this Paper has been written. An attempt has been made to reduce the power plant engineering to plain science and to show the care, knowledge and painstaking development that has gone into the design.

The second world war resulted in tremendous progress in aeronautics and while, during the war, the major factor was the aircraft efficiency as an offensive unit, that was not to say that reliability and passenger comfort were ignored.

The important point now is to learn from the past and apply this new knowledge to future Civil aircraft designs.

Volumes have been written on the performance aspect of aircraft and power plants but little or no explanation has been given of the designer's constant care for passengers' safety and comfort. It is this aspect which it is now proposed to cover for both piston and jet power plants; the subject being grouped under the general headings of:—

(*a*) Design regulations.
(*b*) Reliability.
(*c*) Fire Prevention.
(*d*) Noise.
(*e*) Vibration.

DESIGN REGULATIONS.

Criticism of the regulations limiting design is made in the Paper but never without a constructive alternative, as it is considered that many of the existing memoranda have been formulated to cover a factor of ignorance instead of factual engineering knowledge. The advent of the jet engine and the contraction of distance has resulted in a need for power plants suitable for both tropical and arctic conditions, which in turn has made us search for a truer knowledge of the climatic conditions of the World. In defining these as a guide to design it is necessary to bear in mind that they should be practical conditions not only met one day a year. It is obviously possible to find places in the World where

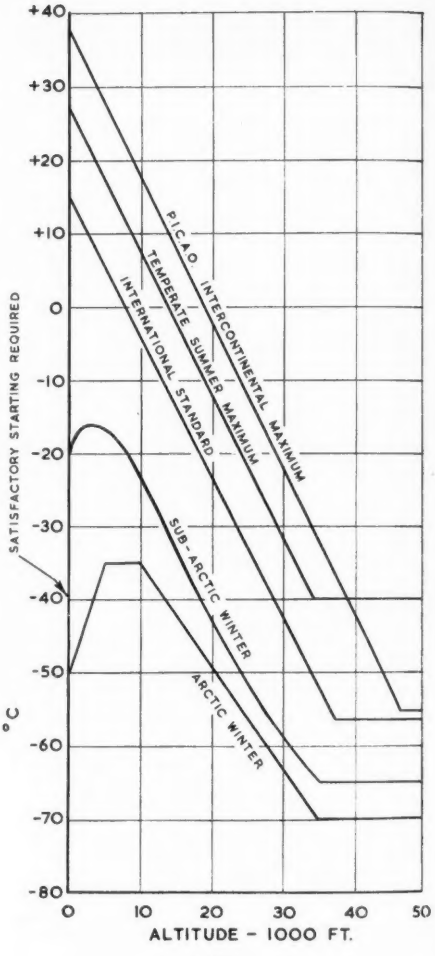

Fig. 1.

Temperature limits for operation. Standard atmospheric conditions. Air density at S.L. (barometer 29.92 in. temp. 15°C.)=0.07652 lb./cu. ft.

ground temperatures are at +50°C. and −50°C., but would Civil aircraft be expected to be designed to cover these extremes? Surely some reasonable figure can be taken. The I.C.A.O. regulations recommend a maximum of 37.7°C., as shown in Fig. 1, but there is still a school of thought in England asking for 45°C.

Again, the regulations ask for satisfactory starting at −50°C. quite regardless of the fact that even the Government Winterisation

Establishment in Canada has rarely observed temperatures below −40°C. during five years of operation. We have cleared piston engine starting down to −40°C. in a refrigerator but we cannot even find an airfield on which to prove further development in practice.

The meteorologist appears to have been asked for extreme climatic conditions, but this information has not been correlated to the probability of aircraft either operating in these conditions, or being able to live in them.

Having made this criticism of the administrative regulations it is perhaps well to say immediately that there are many regulations which are well proved and should be solidly upheld. In fact, much of what follows only emphasises the importance of the design memorandum being factual and not theoretical.

Although much more can still be said on this subject it is felt that a few of the outstanding items will arise during further discussion of the Paper, and to that extent they can be left to a later stage.

RELIABILITY.

Of piston-engined power plants it may now be said that experience has shown the necessity for obedience in design to certain fundamental laws. To-day power plants have such fundamentals designed into them. It was impossible to realise this in the past as many difficulties were overcome only after the completion of the design, and not initially.

The power plant has a complex structure involving mechanical, hydraulic and electrical forms of engineering besides metallurgy, heat transfer, vibration and aerodynamics. The final design of the total unit is a compromise of all these sciences related to the conditions of usage, such as weather, humidity, heat and cold, altitude, sand storms, and so on. To illustrate this statement it is proposed to explain the development background of some of the major power plant components and to show how reliability has been built into these units.

Let us first consider the radiator and oil cooler. Here we have heat transfer associated with hydraulics, aerodynamics, metallurgy and vibration. For reliable operation the power plant must work in both arctic and tropical climates where the temperatures may vary, as shown in Fig. 1.

In other words, the cooling and oil systems must function correctly under any of these weather conditions.

The cooling problem is straightforward and divides itself into three sections:—

(1) The engine powers and its related heats to coolant and oil.

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HEAT TO BE DISSIPATED BY ENGINE COOLING SYSTEM

Power Rating	S/G Gear	Altitude	B.H.P.	Heat to be Dissipated—H.P.		
				Heat to Coolant	Heat to Oil	Heat from Charge
Maximum take-off 3,000 r.p.m. + 20 lb.	MS	Sea-level	1,725	674	87	82
Maximum Climbing 2,850 r.p.m. + 14 lb.	MS	Sea-level	1,395	570		
	MS	7,000 ft.	1,480	589	64	61
	FS	17,500 ft.	1,405	591		96
Maximum cruising 2,650 r.p.m. + 9 lb.	MS	2,000 ft.	1,110	472		37.6
	MS	10,000 ft.	1,175	485	51	41
2,850 r.p.m. + 9 lb.	FS	23,750 ft.	1,165	540		85

Fig. 2.

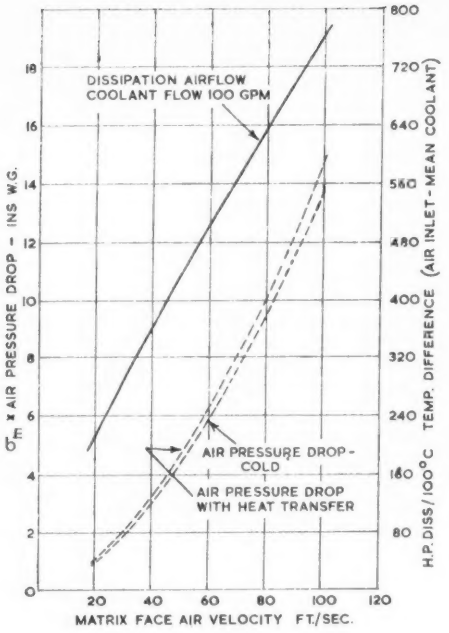


Fig. 3.

Tudor radiator

Matrix details: 4 row "F" type curved tubes; double-edged gills—pitch 13 per in.; frontal area 2.75 sq. ft.

Test conditions: Coolant 30 per cent. glycol; mean temp. 80°-85°C.; air inlet temp. 20°-25°C.

All results corrected to I.C.A.N. ground level conditions.

(2) The aircraft climb and cruise speeds for given engine powers.

(3) The wind tunnel heat transfer characteristics of the cooling units.

Item (1) can be obtained from test bed trials of the engine, as shown in Fig. 2.

Item (3) can be taken from definite wind tunnel data, as shown in Fig. 3.

Item (2) has to be obtained from the aircraft constructor and is a matter of matching the engine powers with the aircraft drag.

Here two major factors are required, the first is the A.S.I. of the best rate of climb, and the second is the estimated maximum cruise speed for maximum cruise power at maximum altitude and weight.

As the engine is developing maximum power on a climb for a minimum aircraft speed this is often a critical cooling case, but the most important condition is to obtain minimum drag under normal cruising.

It will usually be found that if the smallest radiator necessary to satisfy the climb case is used, a high drag results when cruising. This is illustrated in Fig. 4 where it will be seen a radiator of 3 sq. ft. frontal area costs 60 h.p. in drag as against 25 h.p. for a radiator of 5 sq. ft.

Such an analysis shows that the problem of engine cooling is clearly understood and no over-heating of the power plant should occur.

While the understanding of engine cooling has been clarified, development has proceeded rapidly on the type of matrix used, and it is of interest to note the past, present and future of radiator design.

Fig. 5 shows the features of importance, from which it will be seen that the cooling

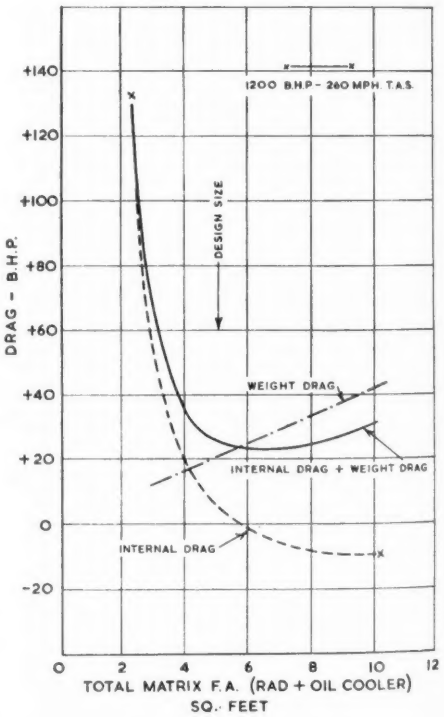


Fig. 4.

Griffon 57 power plant.

Minimum internal drag and weight drag of cooling units on cruise: 1,600 ft. F.S. gear. I.C.A.N. conditions. Coolant temp. controlled to 100°C.

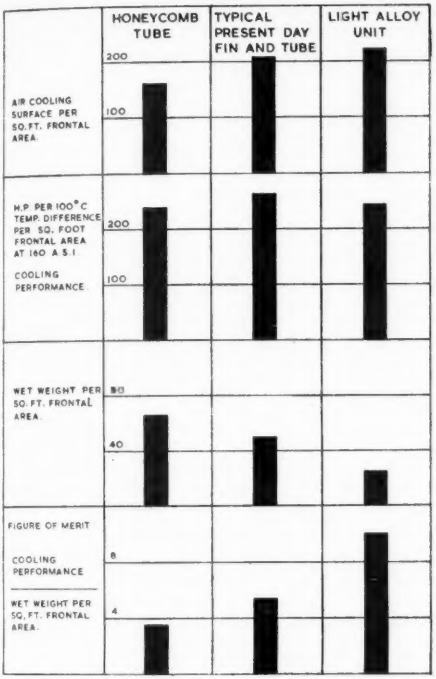


Fig. 5.
Comparison of various types of radiators.

performance per unit of weight has improved from 3.5 pre-war to 5.5 to-day, with the prospect of 10 to-morrow.

This prophecy is no idle dream but merely incorporates the use of light alloy radiators and oil coolers. In America such oil coolers

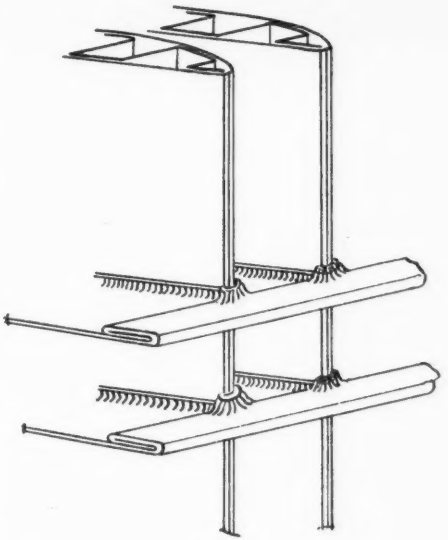


Fig. 6.
Arrangement of double-edge gill which is notched and soldered to assembly on tubes to obtain frontal strength.

are already in mass production, and should be in Great Britain shortly.

The radiator development is largely a chemical and metallurgical study and units are already made and undergoing flight trials.

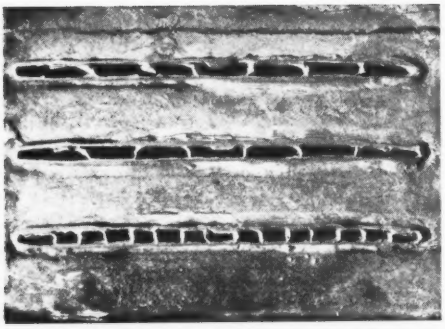
The metallurgical problem is the manufacturers' worry of producing brazed light alloy units in thin strip material.

The chemical issue is that of ensuring that the corrosion of the aluminium water-glycol passages will not reduce reliability.

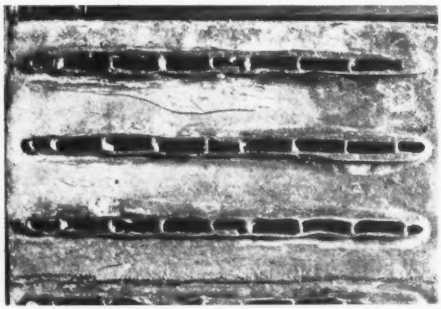
CORROSION PRODUCTS OF COOLING SYSTEMS

	Copper System Standard Coolant		L.A. System Standard Coolant	L.A. Intercooler Rad. Cu. Intercooler NaMbt in coolant
	a	b		
Running Time	104	420	800	700 hours
Appearance	Blue	Green	Orange Yellow	Orange Yellow
Percentage Ethylene Glycol	30	55	31	29
Ph. Value at 18°C.	6.78	6.10	6.90	7.29
Percentage Copper	0.045	0.07	Slight Trace	Nil
Percentage Insoluble matter	0.028	0.002	0.002	0.001

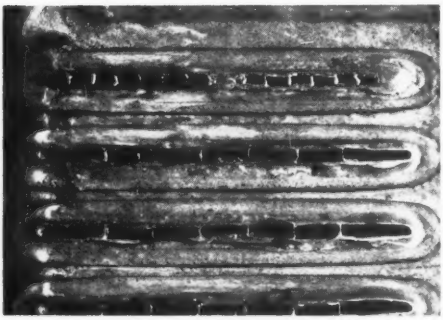
Fig. 5 (a).



Initial type of block: Only close pitch stiffener in outside tube.



Intermediate type: With solid ends to corner tube.



Final type: Stiffened corner tubes and ends. Reinforced tube plate.

Fig. 7.
Stiffening of corner tubes of radiators.

Endurance tests, as shown in Fig. 10, have now been made up to 800 hours on both pure aluminium and mixed copper aluminium systems using "Captax" inhibited glycol to compare with existing 400 hour flight trials of normal copper cooling systems. Fig. 5 (a) compares the corrosion products found and shows conclusively that no excess corrosion need be expected with the light alloy systems.

To change from copper to aluminium cooling units on a four-engined aircraft may well save 900 lb. of payload. Also, it will be appreciated that this weight saving and reliability are being achieved with steadily decreasing drag when it is realised that the surface of the cooling units is approximately 4,000 sq. ft., or about equal to the total wetted area of the aircraft surfaces.

Early in the war structural failures of radiators occurred because of racking stresses at the corner tubes of the blocks, this being eliminated later by stiffening of the corner tube and its attachment to the tube plate, as seen in Fig. 7. Later it was found that occasional severe hailstorms damaged the gill front edge and this had to be doubled and trebled over and then supported by the front edge of the tube, as shown in Fig. 6.

Finally, it was necessary to free the radiator from vibration and from any power plant structural stresses by mounting the units on rubber bungs, as shown in Fig. 8. This finally eliminated any such failures.

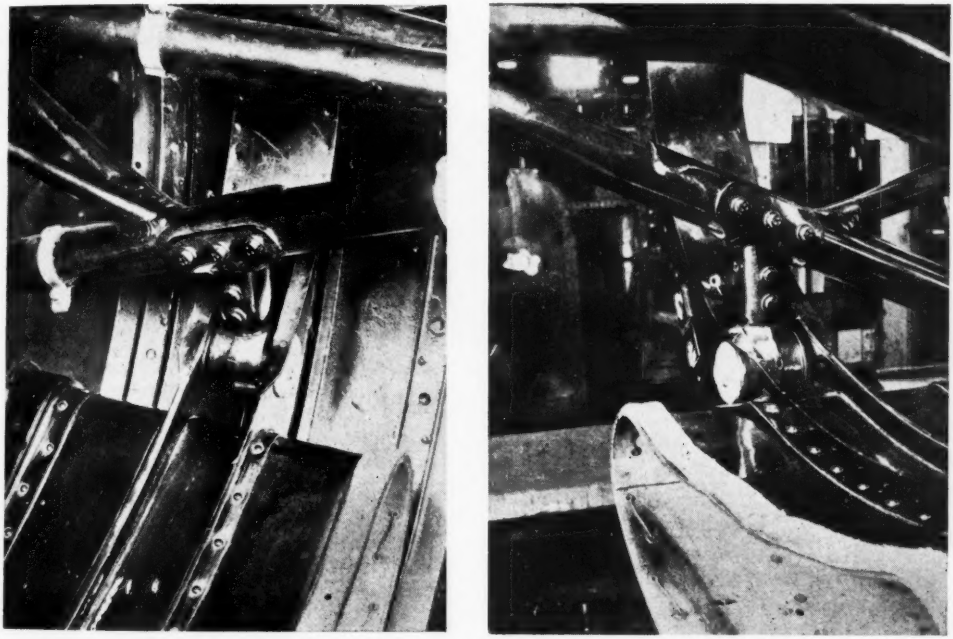
In addition to these structural modifications the radiator inspection testing was improved from just air pressure under water testing to include pressure cycle testing associated with vibration, as shown by the rig in Fig. 9.

Lastly, the prototype radiator is sectioned as a check on hidden flaws associated with the normal soft-soldered construction, although this is gradually being replaced by the brazed methods which can be furnace-controlled.

Associated with the radiator and oil cooler are the coolant and oil flow problems, and a careful study of the hydraulic system has been necessary, for instance, at altitude to prevent cavitation of the pump, hydraulic hammer, and such like, and to study the efficient design of flexible pipes. Complete rigs have been set up with cooling and oil systems as fitted in the aircraft, in order to ensure freedom from these troubles, as shown in Figs. 10 and 11.

The oil tank and engine sump are also made to operate at altitude conditions to obtain satisfactory engine breathing, scavenging and air separation in the oil tank hot pot, as shown in Fig. 12.

The oil system has been further complicated by the need for satisfactory cold starting at −40°C. This is done by diluting the engine lubricating oil with petrol up to 30 per cent. Naturally, initial engine breathing is somewhat difficult on re-starting after such dilution and the breather system has to be carefully designed. The whole problem of winter starting is the subject of



Radiator mounting structure.

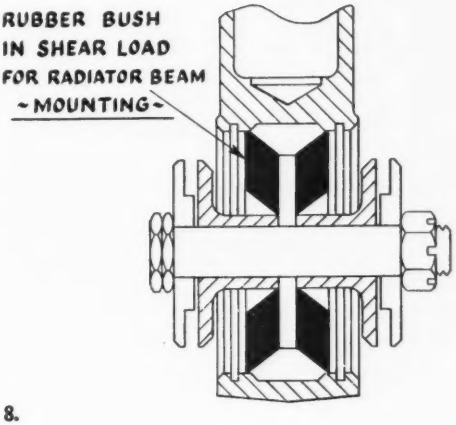


Fig. 8.

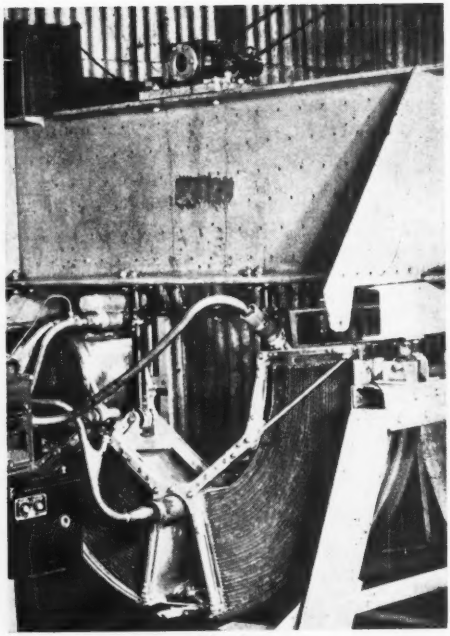


Fig. 9.
Vibration rig used for proving radiator construction.

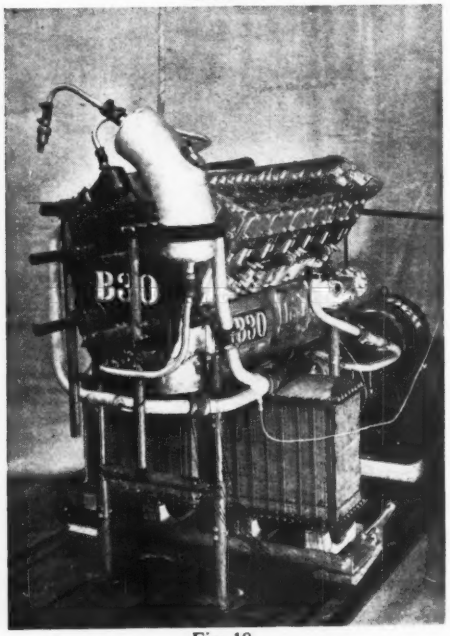


Fig. 10.
All aluminium coolant system rig.

special tests being made in Canada under the direction of the Ministry of Supply and much useful information is being obtained. Without this data oil tanks would have been used in which the oil would have solidified in the major portion of the oil tank and seized the engine after the hot pot oil had been used.

It has been shown how the radiator and oil cooler are designed to give minimum drag, but because of varying flight conditions, including engine powers, temperatures and altitudes, what may cool the engine in tropical conditions may over-cool it in winter. For this reason automatic cooling temperature control is used to operate the radiator flaps, ensuring that the internal cooling drag is always kept to the minimum value relative to the engine operating limitations. The control works through a temperature sensitive phial which relays to a servo power unit the actual temperature of the engine. This power unit is virtually an electrical contact system which "inches" to and fro and operates either the pneumatic ram or an electric actuator to control the radiator flap (Figs. 13 and 14). These components have to pass endurance tests which cover Arctic and tropical conditions, including sand and rain storms, with high overload factors, while being subjected to vibration as well.

A difficulty with the rams was to make them air-tight under Arctic conditions, while with actuators soldered joints and brush wear were the major features. To-day there is no real reason why actuators cannot run 1,000 hours without even inspection, and rams have already proved satisfactory in operation without air leakage down to $-40°C$.

Another interesting item is the engine mounting. For years this was made of tube sizes decided by the theoretical calculation of load distribution at the engine feet, and so on. To-day new designs are tested on a rig (Fig. 15). Loads can be applied as in the aircraft and not only can the deflection be measured but also, the stresses in the various members. Tests have indicated that an excessive safety factor has been used in all old mountings and hence, a substantial weight saving can be achieved.

In the early days of the 1939-45 War we were in serious trouble with fuel systems; engines cut out at altitude because of fuel pump cavitation. An immediate step was to pressurise the fuel tanks, but later came the development of booster pumps, and to-day it is possible to guarantee the fuel delivery to

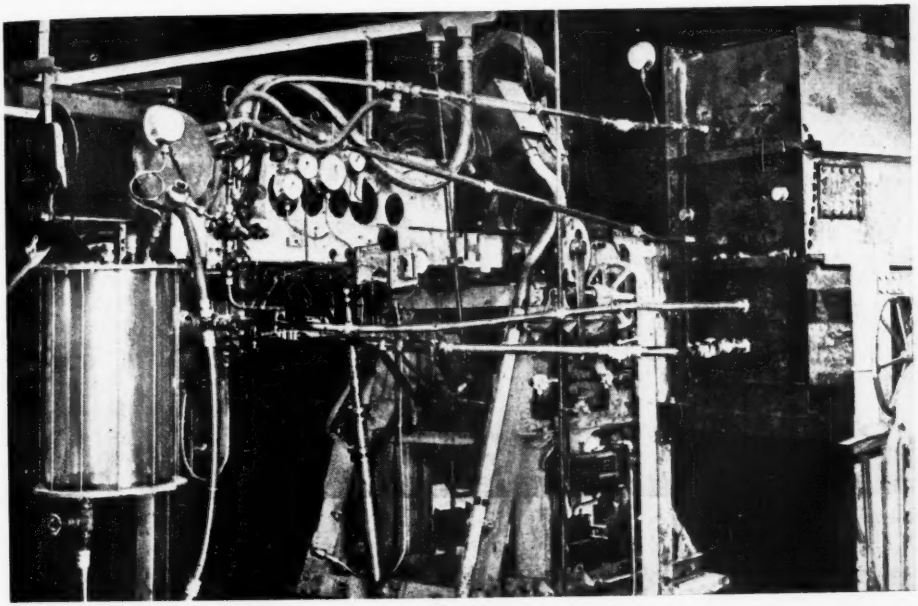


Fig. 11.
Oil system rig.

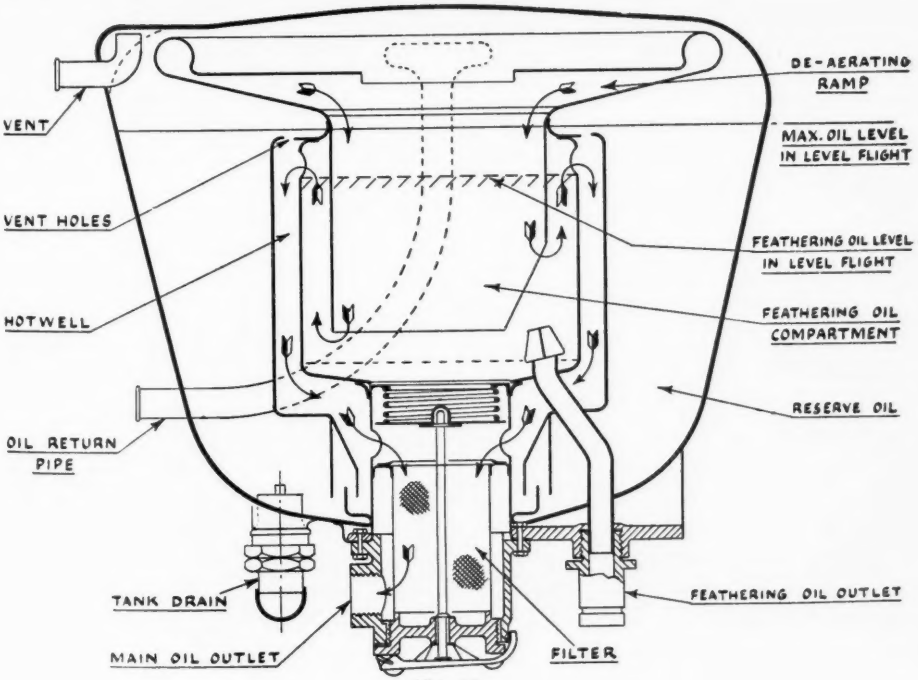


Fig. 12.
Oil tank hot pot design (hot feathering).

the engine even if the fuel is boiling. A section of a pump is shown in Fig. 16, and Fig. 17 shows the boiling of the fuel during a climb to altitude.

Another system of great interest, and one which has necessitated considerable development, has been exhaust assembly. During the war this involved two problems, first that of obtaining maximum power from the engine, and second that of providing a complete black-out for bombers. The first solution was reached by the now well-known stub ejectors which, as applied to the Spitfire, increased the aircraft speed by 30 m.p.h. They also have a very fine reliability record for a minimum of weight.

The second problem of flame damping is not nearly so simple. To prevent flaming, the temperature of the gas has to be reduced to 400°C. and this was found to be impos-

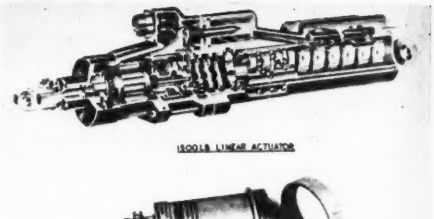


Fig. 14.
Pneumatic ram and electrical actuator.

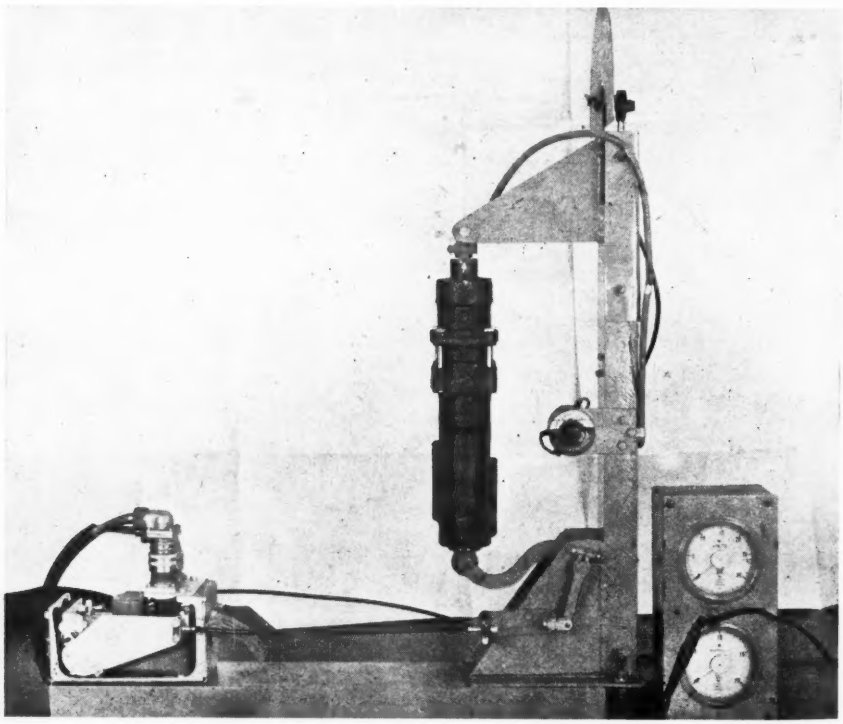


Fig. 13.
Automatic inching control and actuator.

sible by an air blast over the stubs, already mentioned. The final solution was reached by thinning the exhaust stream to approximately 0.3 in. wide, which resulted in it becoming chilled by the cooling air blast.

Flaming was also created by the impulses from the stubs, and it was necessary to pass the exhaust into a common manifold before allowing it to reach the fishtail outlet.

During the war this manifold had to be masked because of the red hot glow at night, still further complicating the cooling problem of the material used. It was found that Inconel and stainless steel were the only two materials to stand up to these conditions and even then they should not be allowed to work above 750-800°C. The reason for this is shown in Figs. 18 and 19 which indicate firstly, the reduction of strength, and secondly the scaling effect at high temperatures.

The background of the exhaust system has been mentioned here because in initial civil power plant types stub ejectors have been used. This has been largely due to their greater ejector thrust and lighter weight, but to-day they are having to be replaced by tail pipes in order to reduce the noise level.

This in turn has reflected back on the high metal temperatures on such types as manifolds and tail pipes, and to-day cast finned units are being developed with low cooling drags and also reduced operating temperatures, and consequently, increased life. As a check on the temperatures, "Thermindex" paint is used which gives a clear indication of any hot spots, as shown in Fig. 19 (a).

When the component testing and development has been done the units are assembled into the complete power plants which are mounted on wing hangars and tested with their correct propellers, as shown in Fig. 20. Complete endurance runs are made of 500 or 1,000 hours under conditions parallel to the normal flight programme from, say, England to Australia or Canada. This work is finally duplicated by checks on flying test beds, as

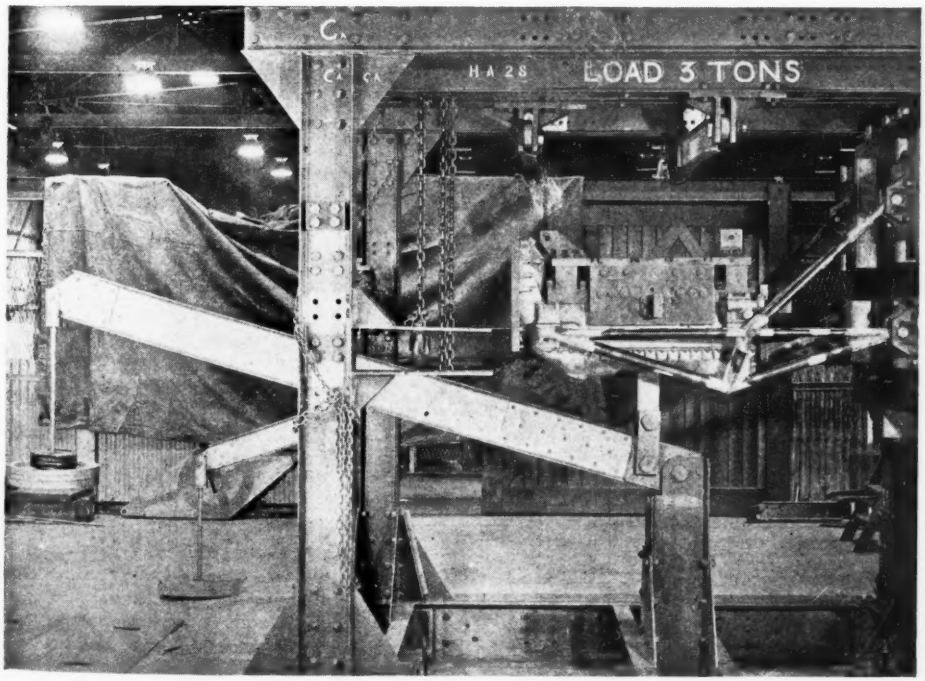


Fig. 15.
Engine mounting rig.

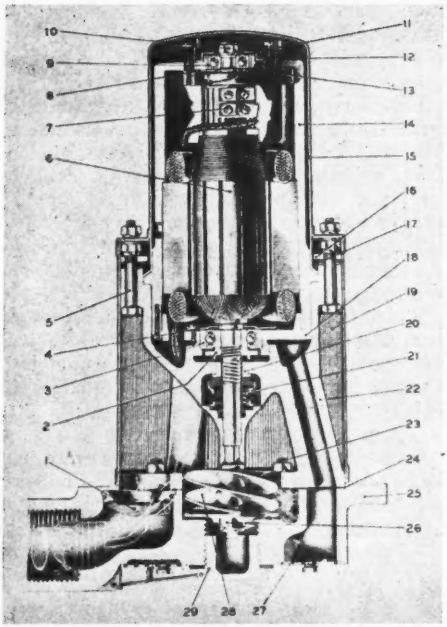


Fig. 16.
Fuel system booster pump.

shown in Figs. 21 and 22. At the end of these tests the power plants are stripped, laid out on inspection tables and critically examined. Where necessary, modifications are made and after final satisfactory running the power plants are released for mass production.

FIRE PREVENTION.

All possible steps are being taken to achieve maximum reliability, whether this be considered from the aspect of:—

(1) Manufacture of the product.
(2) Additional understanding of the problem, or
(3) The performance aspect of satisfying the various requirements of the engine.

This is still not enough if a fire breaks out in the power plant and to make sure that even this eventuality is catered for, in the design, a careful study has been made of power plant fires. These have been deliberately created in complete power plants with the object of studying the problem to ensure firstly, that a fire is indicated to the pilot; secondly, that if it occurs adequate time is available for shutting down the engine and operating the fire extinguisher before the fire gets out of control; and lastly that the extinguisher system is capable of putting out a fire no matter where it is created in the power plant.

Let us consider the power plant features which may be called a hazard. In general these are covered within the scope of the oil and fuel systems and the most important items are common to both and can be considered as the pipe runs.

It is becoming accepted that all pipe runs where possible should be of solid drawn steel with screwed end connections wire locked. Unfortunately, such a statement has to be modified in practice, firstly because of engine movement due to vibration relative to the bulkhead, and secondly because of thermal expansion. This latter feature applies to the jet engine, and the former to piston engines. In either case the solution is found in the use of flexible connections, the wartime development of which provides an interesting example of the constant progress towards the ultimate ideal in reliability. None of the early types of hoses proved satisfactory in that they all leaked when submitted to fire tests. Now they have all been superseded by reinforced rubber hoses with steel swaged ends fitted with screwed couplings.

The fire requirements of the Civil specification of fuel and oil hoses calls for a five minute test with a flame of 1,000°C. under operating hydraulic conditions inside the pipe.

British manufacturers to a large extent comply with this specification, but the procedure laid down to carry out a test allows too much latitude when compared to the actual fire trial results. The flame itself can be varied considerably within the limitations of the specification, the concentricity of the hose laminations has to be carefully controlled to obtain consistent results and finally, the test of the hose itself is of little good if the end connections are not equally fire resistant. In actual fact, fire tests on the end connections will invariably fail the hose in about half the time specified. It is suggested that the specification should be modified to include a test on the end connection as well.

Experience has shown that a much more consistent result is obtained if a 6 in. diameter flame is used instead of one varying with the

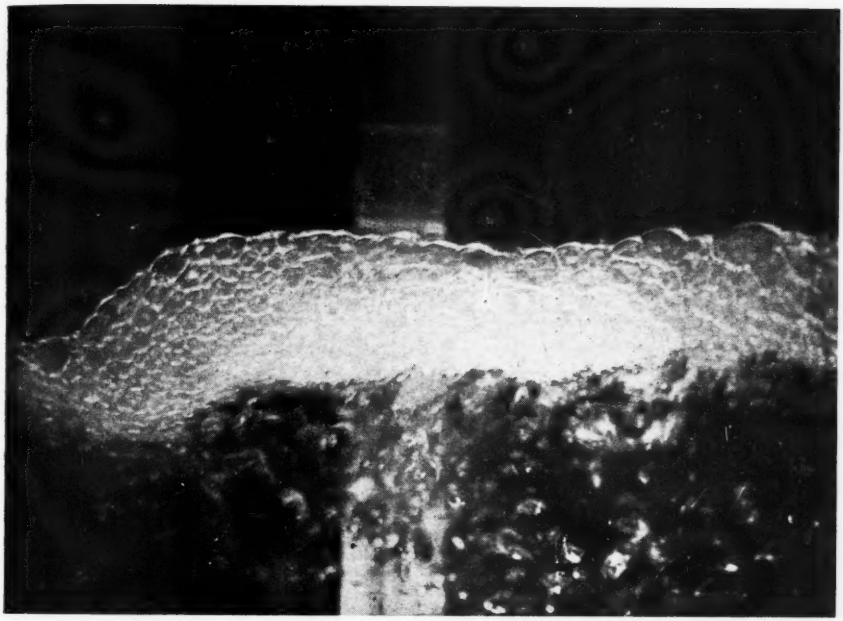


Fig. 17.
Fuel boiling in tank at 20,000 ft.

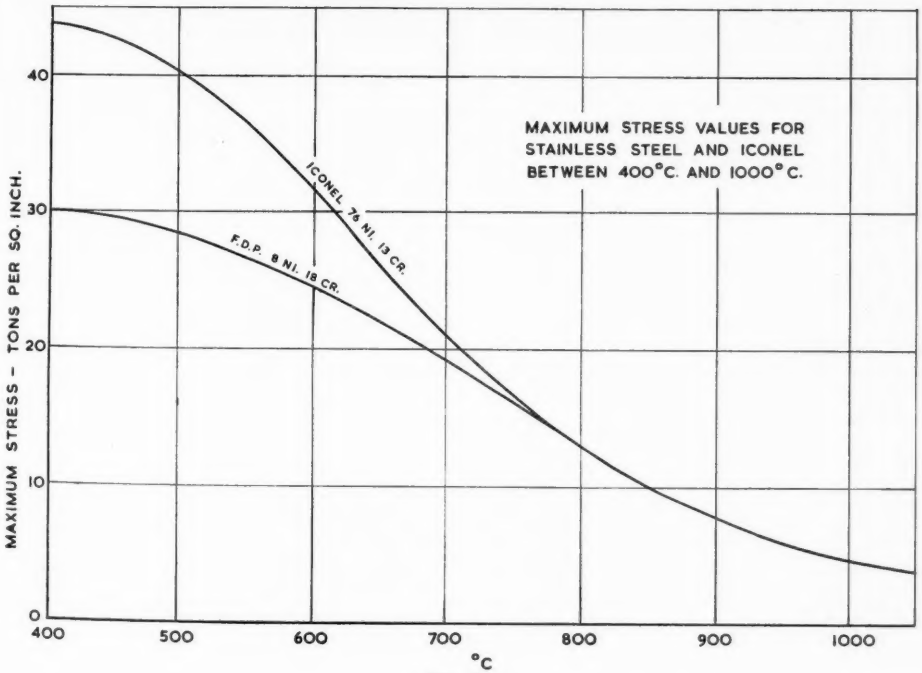


Fig. 18.

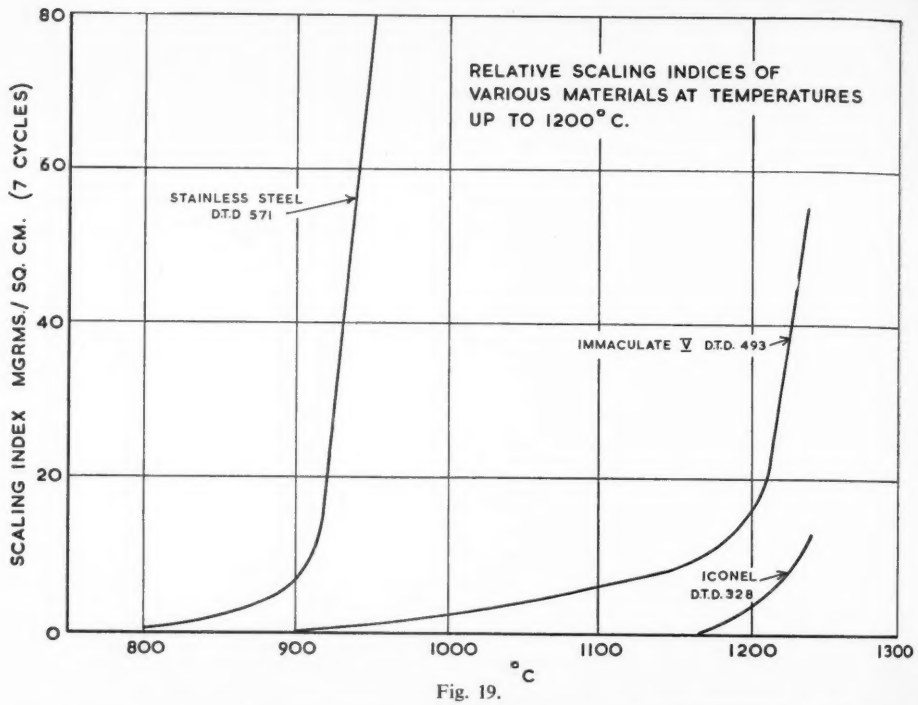


Fig. 19.

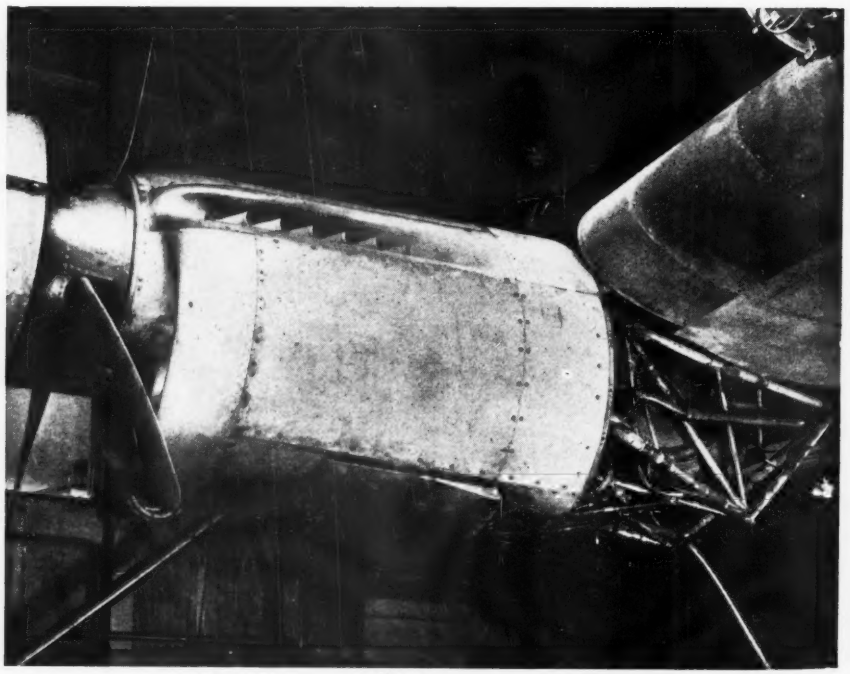


Fig. 20.
North Star hangar testing of power plant.

pipe diameter. Such changes would probably mean a reduction of the time called for in the flame from five minutes to two, but would give a much simpler test easily applied by the manufacturers in view of the constant test conditions required.

Although flexible hoses definitely withstand the official fire tests, only the shortest possible lengths are used in practice as otherwise they involve a severe weight penalty, as they are more than twice as heavy as steel pipes and their large diameter makes their installation by no means easy.

An interesting side light of this hose development is that the fireproofing is not the only criterion of a satisfactory hose; it must be flexible at temperatures of −40°C. and still useful if occasionally exposed to temperatures up to 120°C., besides being unaffected by various fuels and oil inside the pipe.

An interesting and little known characteristic of hoses is the age-hardening effect, particularly in relation to the temperature factor. This is shown in Figs. 23, 24 and 25. All these items have to be given careful consideration when a pipe layout is made.

Returning to the subject of fire prevention, one could continue to detail the tests necessary to guarantee maximum safety, but sufficient has been said to indicate the careful consideration that is being given to all doubtful items. However, if a fire occurs the first essential is to give the pilot warning, and the second is to be certain that the fire can be contained in front of the bulkhead and finally, extinguished before it obtains too great a hold of the power plant.

Experience has proved that bulkheads should be in steel supported by top hat stiffeners also in steel and not light alloy. Cases have been found where light alloy

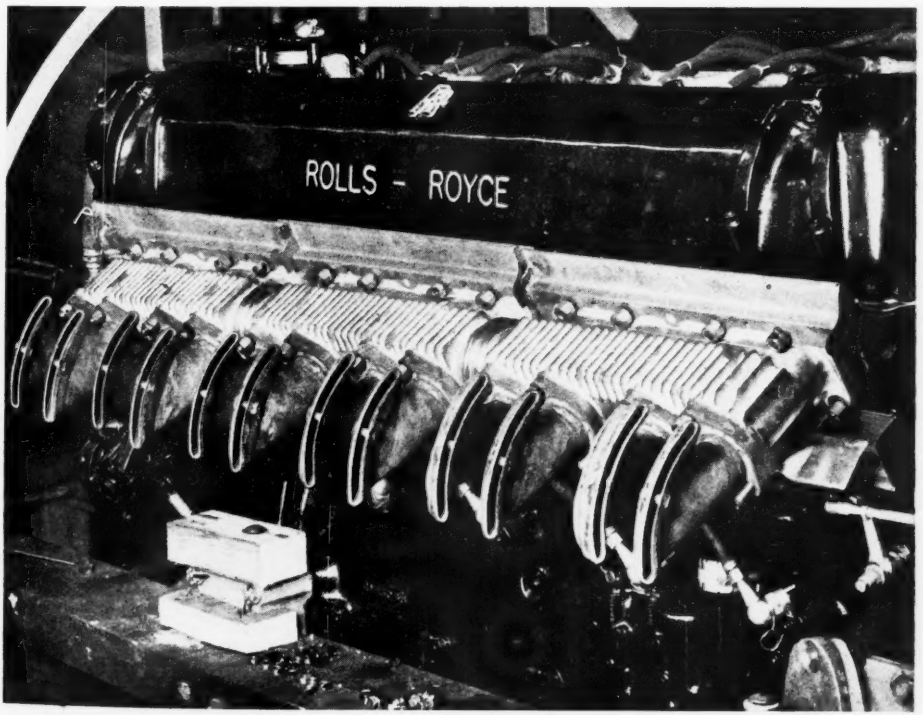


Fig. 19 (a).
Cast manifolds and flame damping stubs.

Fig. 21.
Lancastrian Nene "icing" flight trials.

Fig. 22.
Tudor and North Star flying test beds.

stiffeners have split and light alloy rivets melted, allowing bad distortion of the bulkhead with the risk of fuel and fire seeping behind into the airframe.

Similarly, the engine controls on the bulkhead should not be of light alloy as this may melt away and not allow the closing of the engine throttle.

Again, fuel filters should be behind the firewall as the light alloy cases may melt or the joint leak, creating excellent auxiliary fires.

So much for the fire precautions covering individual components.

The next item is to ensure that the pilot has adequate warning of a fire and can take the necessary action. To this end detectors are fitted around the most vital parts of the power plant. These operate a red lamp in the feathering button of the airscrew for the power plant concerned and constitute a definite warning to the pilot to shut down the engine and feather the propeller. The detectors are of several kinds, but it is considered that the repeating types are best as the feathering light will go out if the fire is extinguished and re-light if a re-strike of a fire should occur. These types also enable the system to be readily checked so that a guarantee of their functioning satisfactorily is always possible.

One popular type of detector works on a thermocouple principle but needs a sensitive relay to operate the lamp. Other types operate on capillary instruments. In general it is considered that there is plenty of scope for improvement in the types available.

Hose cracked after 27 hrs. ageing at 160-170°C.

After 29 hrs. 30 m. at 85°C.—bend rad. .625 in.
Hoses after ageing tests.
Fig. 23.

Our power plant fire experiments have shown that the detectors operate in less than two seconds; this would, of course, depend on the magnitude of the fire.

The pilot's action on seeing his red light is to close his throttle, feather the airscrew, shut

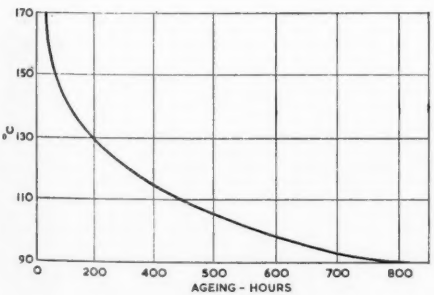


Fig. 24.
High temperature—Life.
Basic temp./life. Characteristic curve.
Conditions: Dry. Points plotted where bending to twice min. bend. radius will produce defects to cause rejection.

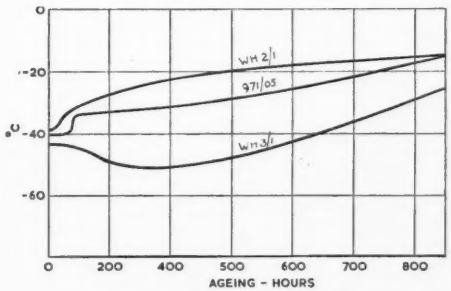


Fig. 25.
Low temperature—Life.
Basic low temp./ageing. Characteristic curve of hoses.
Conditions: Dry inside and out; ageing temp. 90°C. Brittle points plotted where bending to twice min. bend. radius will produce defects to cause rejection.

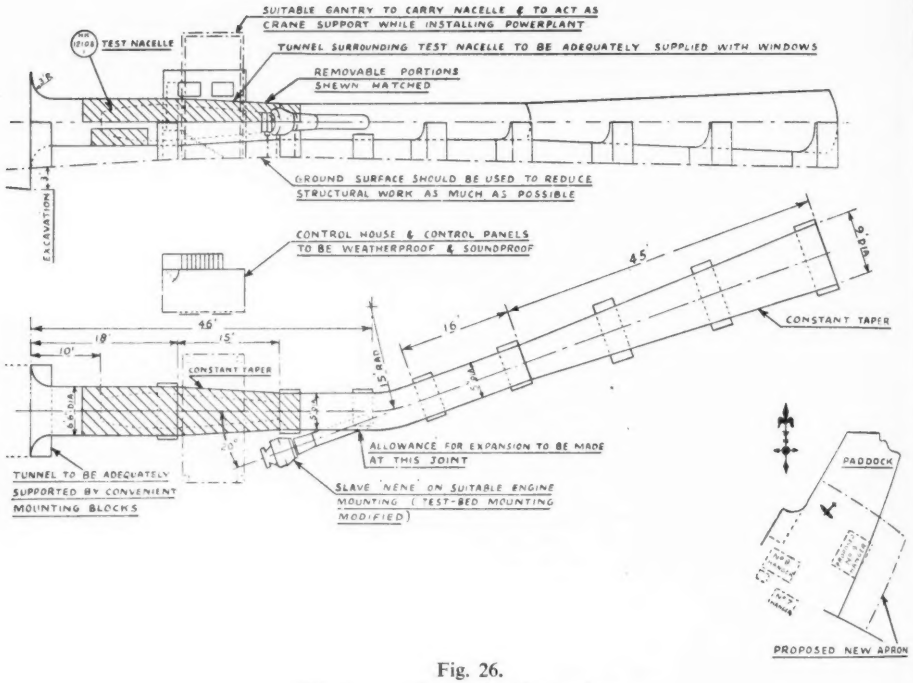

SUITABLE GANTRY TO CARRY NACELLE & TO ACT AS CRANE SUPPORT WHILE INSTALLING POWERPLANT
TEST NACELLE
TUNNEL SURROUNDING TEST NACELLE TO BE ADEQUATELY SUPPLIED WITH WINDOWS
REMOVABLE PORTIONS SHEWN HATCHED
GROUND SURFACE SHOULD BE USED TO REDUCE STRUCTURAL WORK AS MUCH AS POSSIBLE
EXCAVATION
CONTROL HOUSE & CONTROL PANELS TO BE WEATHERPROOF & SOUNDPROOF
CONSTANT TAPER
ALLOWANCE FOR EXPANSION TO BE MADE AT THIS JOINT
TUNNEL TO BE ADEQUATELY SUPPORTED BY CONVENIENT MOUNTING BLOCKS
SLAVE 'NENE' ON SUITABLE ENGINE MOUNTING (TEST-BED MOUNTING MODIFIED)
PADDOCK
PROPOSED NEW APRON

Fig. 26.
Fire tunnel for testing jet engines.

off his fuel and oil and then press the fire extinguisher button. The propeller should stop within 15 seconds of feathering the airscrew, and the fire should be out six seconds later.

Tests have been made to prove that the distribution of the extinguisher is adequate by setting up skeleton rigs and noting the distribution. This has entailed a careful study of the pipe sizes and distribution holes to enable a full bottle of extinguisher to be ejected in the required time limit.

Another factor of importance in the case of fire is the short feathering time, and while much work remains to be done within the airscrew design, experience has also shown that a big step in the right direction is achieved by the use of feathering oil supplied from the oil tank hot pot through the main engine filter (see Fig. 12).

Until recently almost all systems have used cold unfiltered oil from the body of the oil tank.

In order to prove that fires can be extinguished in power plants an old Lancaster aircraft has been fitted with various marks of engine installations (one of which is shown in Fig. 27). These have been deliberately fired to prove that the fire could be extinguished. The power plant on test was placed in the slipstream of another aircraft to reproduce the flight condition and then, while the test engine was running at normal cruising power and cooling and oil temperatures, fuel and oil were sprayed into the power plant for 30 seconds at rates up to 120 to 180 gallons/hour respectively. Petrol was then ignited and the fire allowed to burn for 20 seconds while still pumping fuel and oil into the power plant, and the normal fire drill was then initiated. The detectors had obviously indicated a fire long before this.

One important point discovered was that if a good fire did occur and was extinguished, a re-strike of the fire might break out if the oil, for instance, had not been shut off. This needs emphasis as aircraft are only just being fitted with shut-off cocks on the oil system and in many cases even fuel systems do not have shut-off cocks at the bulkhead.

Another point of interest was that on Tudor and North Star power plants a fire could be extinguished even when the radiator air flow control flaps were left wide open, although the blanketing effect of the methyl bromide was obviously less effective because of leakage past the flaps.

While there are still a number of items to be completed, it can be said that power plant fires can definitely be extinguished if they occur with piston engine types. On the other hand, we are only just starting to learn the problems of jet engine fires. In this case, with the vast quantities of air consumed, it may be difficult to put out an airborne fire.

Jet engines at the moment are only fitted with a sufficient quantity of extinguisher to smother forced landing fires, that is to say without excessive air flow through the engine. In the future, with the use of high pressure extinguisher systems (400 lb./sq. in.) and very large pipes, it may be possible to blanket the engine and intake for perhaps two seconds and hence snuff the fire without carrying excessive fluid. So far existing British installations only use extinguisher pressures up to 100 lb./sq. in. and in this case it is not possible to blanket the power plant in two seconds in flight.

Attempts are being made to lay down the fire regulations governing the design of jet engine power plants. If this must be done now, it is suggested in all seriousness that the vast experience already built up on piston engine fires should be correlated to jet engine design. As mentioned earlier, we are in danger of being surrounded by theoretical and not practical knowledge. For instance, the auxiliary compartment (zone 1) on jet engines is not allowed to have metal surface temperatures over 175°C. despite the fact that piston engines have been operating for years with metal temperatures of 300°C. round the exhaust system. Why not read across from past experience, instead of relying on theory based on possible ignition conditions of unventilated compartments? The most satisfactory answer in the end will be obtained by making jet engine fire trials similar to those already mentioned on piston

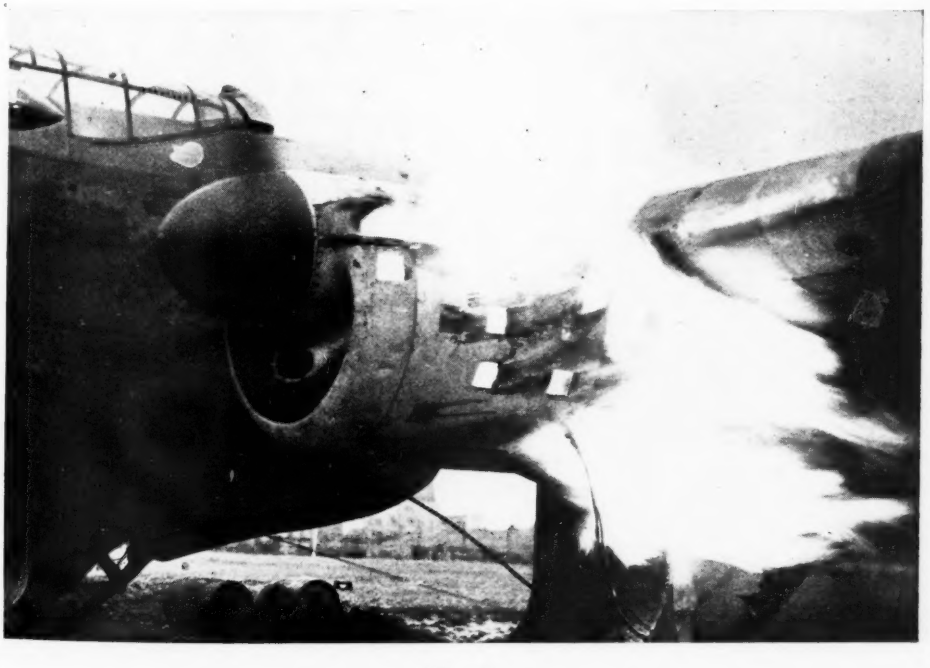


Fig. 27.
Power plant fire extinguishing tests.

engines. Such work has already been initiated and the plan of a fire tunnel under construction is shown in Fig. 26.

With all the existing knowledge and this background of future development there would seem to be no reason why the problem of fire, even with the jet engine, should not be capable of an easy solution.

NOISE.

The subject of noise is a vast one, and within the scope of this Paper it is obviously only possible to deal with a particular aspect of it. To that end it is proposed to consider the effect of the engine and propeller on passenger comfort.

The problem of cabin silencing will be dealt with in an objective manner as factors of absorption and reflection in a cabin are studies in themselves, as also is the subject of accurate recording instruments for noise problems.

In an aircraft there are three main sources of noise:—

The engine.
The propeller.
The airframe.

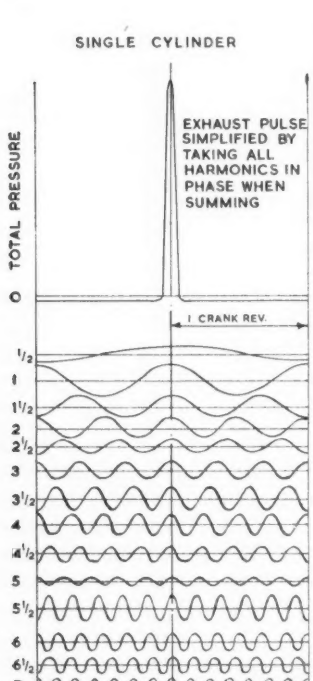


Fig. 28.

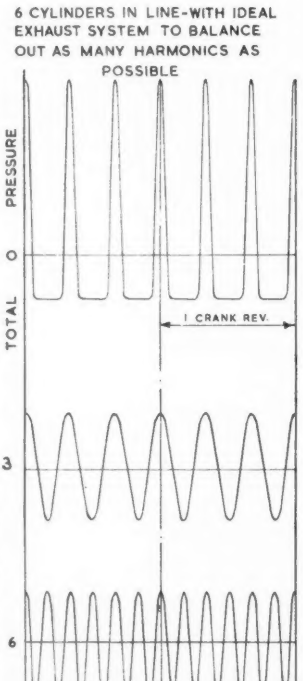


Fig. 29.

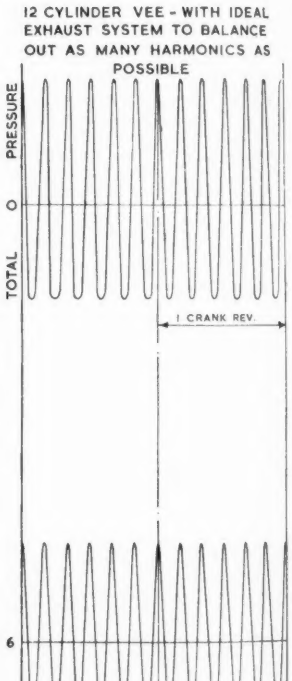


Fig. 30.

Relative pressure amplitudes of exhaust pulse harmonics—four-stroke engine.
The number of a harmonic gives its frequency as a multiple of crank rotation speed.

HIGH FREQUENCY JET ENGINE NOISE LEVELS

Flight on Lancastrian VM 742.

Recordings taken in the centre of the Passengers' Cabin (position H).

Outboard engines Nenes.

Inboard engines Merlin 24's with 3-blade paddle type airscrews (AS/159).
Reduction gear .42 : 1.
Welkin exhaust stubs.

Altitude 10,000 feet.

Readings taken at comparable air speeds.

Nenes only, Merlins feathered.

	10,000-30,000 c/s.	20,000 30,000 c/s.
(1)	At 10,500 r.p.m. 72.5 db.	66 db.
(2)	At 11,000 r.p.m. 72.5 db.	66 db.
(3)	At 11,500 r.p.m. 73 db.	68 db.
(4)	At 12,000 r.p.m. 73 db.	68 db.
(5)	At 12,500 r.p.m. 74.5 db.	70 db.

Nenes idling, Merlins 2850+5.1 *lb. F.S.*

(1)	less than 60 db.	less than 60 db.
(2)	, 2850+9.7 lb. F.S. less than 60 db.	less than 60 db.

Fig. 31.

It is proposed to discuss the engine in particular, although a few important characteristics of the propeller and fuselage need also to be mentioned in their relation to the engine problem.

The major feature in the creation of noise is the exhaust system, whether this be from a piston or jet engine. When an attempt is made to reduce noise it is well to understand what has created it and then to search for a cure. For this purpose the spectrum of noise from a piston engine has been analysed and is shown in Figs. 28, 29 and 30. Fig. 28 may be regarded as the fundamental of a particular type of engine and was obtained on a single cylinder unit.

A theoretical study of this chart shows that with a given number of cylinders, certain harmonics will cancel out. Such information has been checked with the noise from the full-scale engines concerned and has been shown to line up with the noises recorded (Fig. 29).

The analysis has also shown why the tail pipe may be quieter than stub ejectors, and has indicated further lines along which noise reduction can be obtained. Definite improvements can be made over the noise level obtained by plain tail pipes with probably no more actual loss of ejector thrust (Fig. 30).

A study of the noise spectrum on a 12-cylinder engine reveals the fact that the major noise frequencies are in the low frequency region, where they are most difficult to control by sound-proofing the cabin. However, the analysis of these engine frequencies has shown a method by which the problem may be tackled.

Several features of interest are revealed from a study of turbine engine noise. While the piston engine noise is greatest at low frequencies and decreases steadily up to 10,000 cycles/second, the jet engine noise is low at low frequencies and steadily increases, having high noise levels up to 30,000 cycles/second (Fig. 31). It is perhaps wrong to call this a noise level as it is well beyond the aural point, but vibration may have some effect on the life of the engine and the health of the pilot. On the other hand, since it is a high frequency noise a pressure cabin of the usual sound-proof type should give adequate protection.

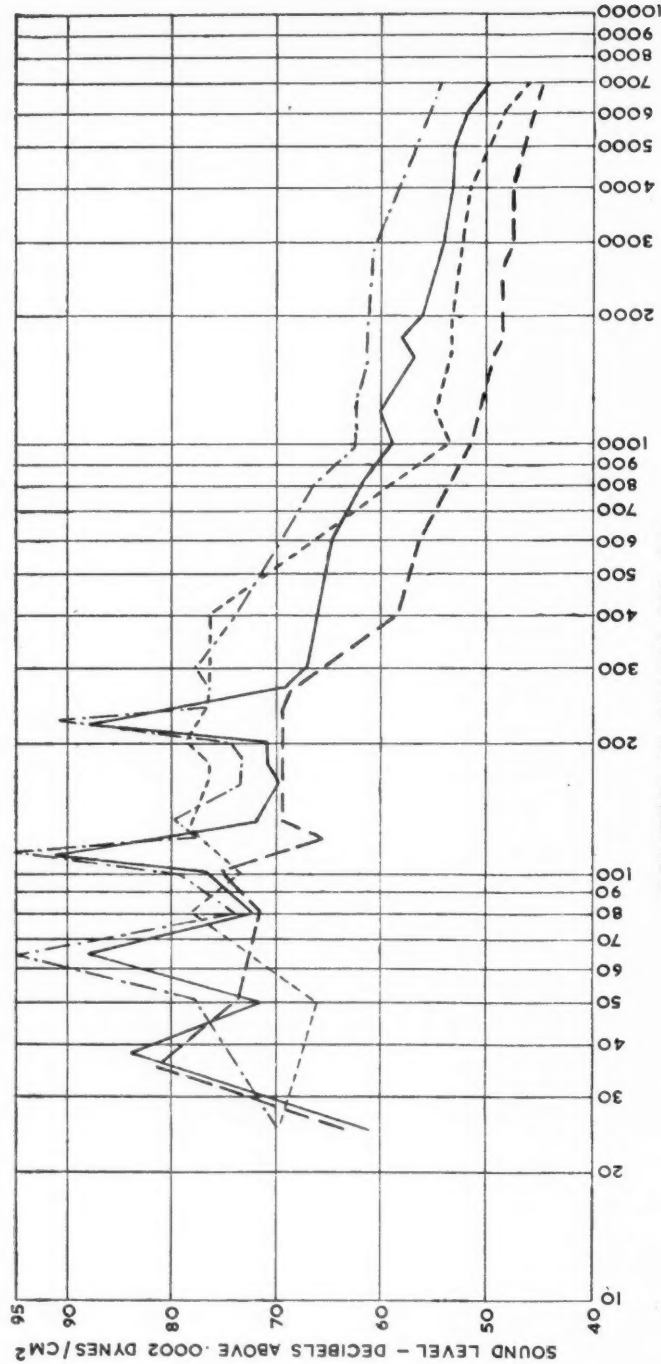


Fig. 32.

Pressurised cabin:
Level flight, 2,200 r.p.m. + 4 lb./sq. in. B.S.T. Short T/P manifold ————————
Glide, inboards feathered, outboards min. revs., 6 F/T manifold — — — —

Standard cabin:
Level flight, 2,200 r.p.m. 4 F/T manifold — · — · — · —
Glide, inboards feathered, outboards min. revs. T.M.C. stubs - - - - - - - - -

The suggestion is, of course, that as the changeover from piston to jet engine occurs so the noise problem will become easier, but this will not mean that sound-proofing can be forgotten. To glide with engines feathered reveals how high is the aerodynamic noise level in most aircraft, and this alone will mean that sound-proofing is necessary (Fig. 32).

To sum up, in the future there would seem to be no reason why the passenger should not be able to fly in as great comfort in an aircraft as in a train or car.

Another problem is that of the passenger on the aerodrome before he flies, particularly with jet engines. In this case the high frequency noise cannot be sound-proofed and it may be that waiting rooms and aerodrome buildings will have to be placed outside the objectionable noise range. Fig. 33 shows a polar curve of noise distribution round the jet engine and it is of interest to note that the jet makes a cone of maximum noise roughly 45° to the jet axis and also, that the noise level does not drop to a comfortable level under a radius of 100 ft. from the engine under take-off conditions.

So far as propellers are concerned, there are a number of fundamentals which require constant attention. Generally an increase in the number of blades for a given horse power will decrease the noise level. This also has another important effect, namely that of increasing the effective frequency of the noise, and since this is of engine exhaust order and

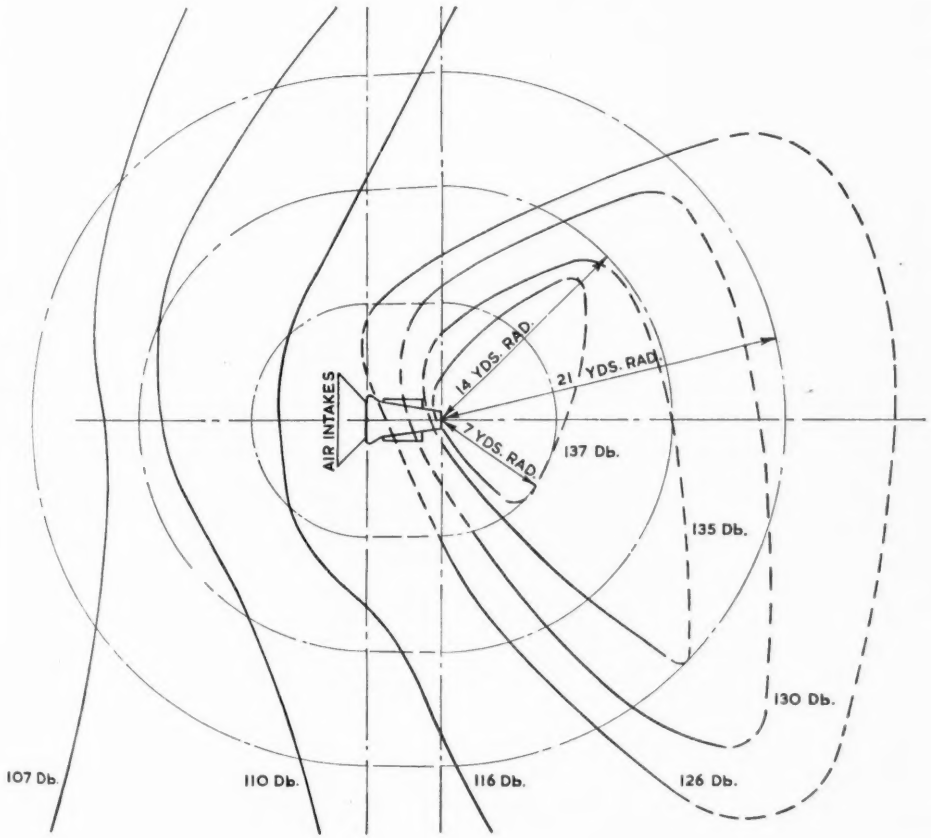


Fig. 33.
Noise contours. Nene static jet unit. 11,000 r.p.m. Figures indicate general noise levels (Db).

consequently very difficult to eliminate by sound-proofing, any increase of the sound frequency will decrease this difficulty. Noise level is a direct function of propeller speed and hence will be of more account with propeller-turbine engines cruising at 90 per cent. maximum speed than with piston engines cruising with 75 per cent. of maximum r.p.m.

Another point of importance often overlooked is the fuselage to propeller tip clearance. This may lead to trouble if the distance is less than nine inches; preferably it should be more than one foot.

Enough is known of the noise problem to enable considerable improvements to be made on future transport aircraft.

VIBRATION.

It will be understood from earlier remarks how much importance has been attached to the subject of vibration on the life of power

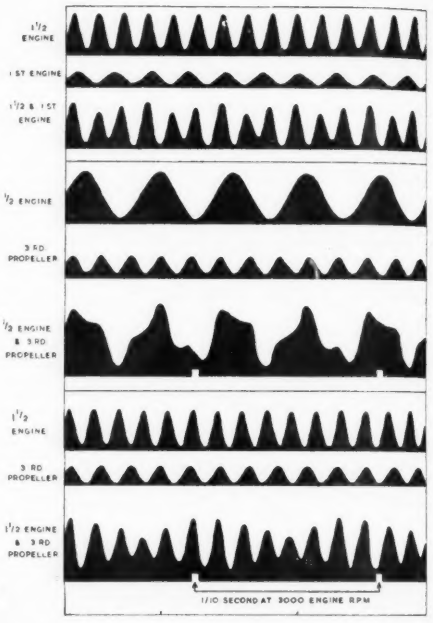


Fig. 34.
Typical variation frequencies and beats found in aircraft during flight.

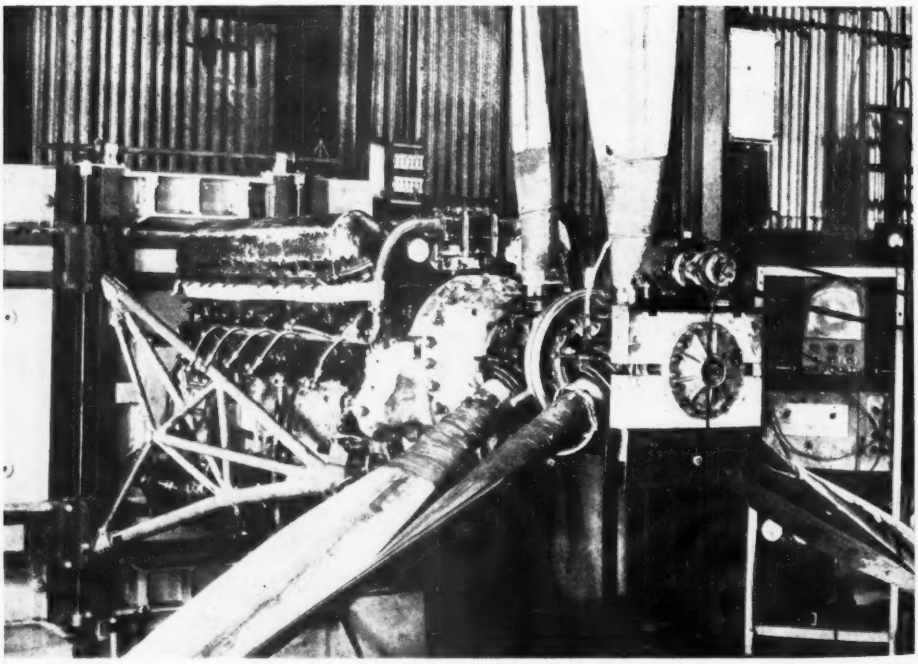


Fig. 35.
Power plant vibration rig.

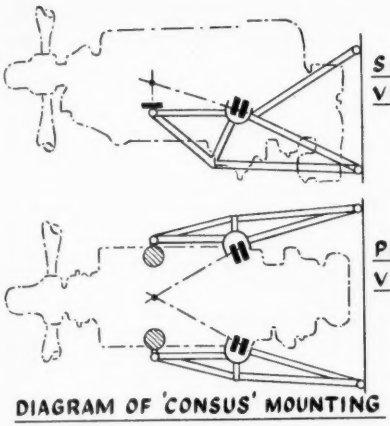


Fig. 36.
Consus mountings.

plant components, but it is well to realise that there is a much bigger issue than just the power plant. Aircraft vibration may come from three sources—airframe, propeller and engine.

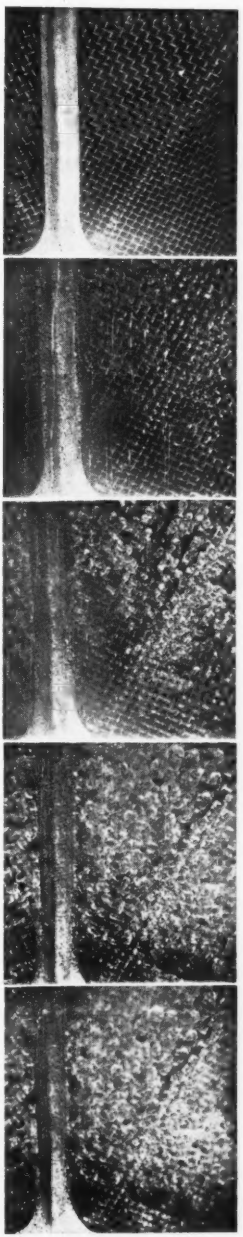
As a result of "carrying the baby" in the past, for vibration troubles in aircraft, a flight technique has been built up which enables the cause of the vibration to be analysed and a cure found.

A vibrograph of a modified R.A.E. type is fitted to the engine mounting feet, or elsewhere, and records the vibration at that point on a photographic film. The record is obtained at varying engine r.p.m. and in the three planes of movement. Fig. 34 gives simple silhouettes of the curves which result, and it is possible to see from these curves whether the vibrations are due to engine, propeller or aerodynamic excitation of the airframe.

Vibration may affect the power plant components, and by reproducing this on the rig it is possible to study the components of the power plant and hence find out whether a flight condition can be expected to create trouble. Fig. 35 shows the complete power plant fitted to a bulkhead and an exciter fitted on the propeller shaft provides the source of vibration and can be made to reproduce the same modes as those occurring at the engine feet during flight.

As a result of these studies it has been possible to evolve satisfactory designs of radiator and header tank mountings. Usually

Nene icing trials.
Water 105 g.p.h. (2 gm./m.³). Alt. 7,000 ft.
A.S.I. 210 m.p.h. O.A.T. −3½°C.



Time from start, mins.	Engine r.p.m.	Jet pipe Temp. °C.	Jet pipe Press. psi.
0	11,500	540	8.72
4¼	11,400	600	6.08
6¼	11,400	635	5.13
8¼	11,450	655	5.08
9½	11,400	670	4.83

Fig. 37. Typical icing data sheet.

in flight, first propeller order vibrations have indicated lack of propeller dynamic balance; while third and fourth propeller orders have shown resonances due to insufficient tip clearance with radiator ducts, air intakes or fuselages. Engine order vibrations have indicated transmission of these to the cockpit and their reduction is covered by the use of Consus engine mountings, the principle used being application of the dynafocal type on radial engines, to the in-line engine. Such a mounting is shown in Fig. 36.

Two examples of vibrations being felt by the passenger and blamed on to the engine, revealed the facts that in one case the vibration was almost constant frequency, even with the propellers feathered, and hence was not due to the engine. In the other case an engine order was found and traced to stub ejector exhausts impacting on the fuselage, the vibration being airborne. The change to tail pipes eliminated this trouble.

From the foregoing it will be seen that many of the problems of vibration are capable of being analysed and hence, of being solved, but the subject is complex and often involves problems of resonance between engines, airframes and propellers. It is strongly recommended that ground vibration tests on new prototype airframes should be enforced in England. This is already a requirement of the C.A.A. in America.

During the war such work was invariably done by the R.A.E. after the aircraft were issuing out on the production line and the compromises effected (so as not to hold up production) were not always the best answers for the vibration trouble. By careful study of the vibration problem in the initial design stages of the airframe, power plant and propeller, it should be possible to eliminate any major issues which would render the passenger vibration conscious.

CONCLUSIONS.

Some reference must be made to the progress being made in jet engine de-icing. The problem was fully described in the Papers read at the Anglo-American Aeronautical

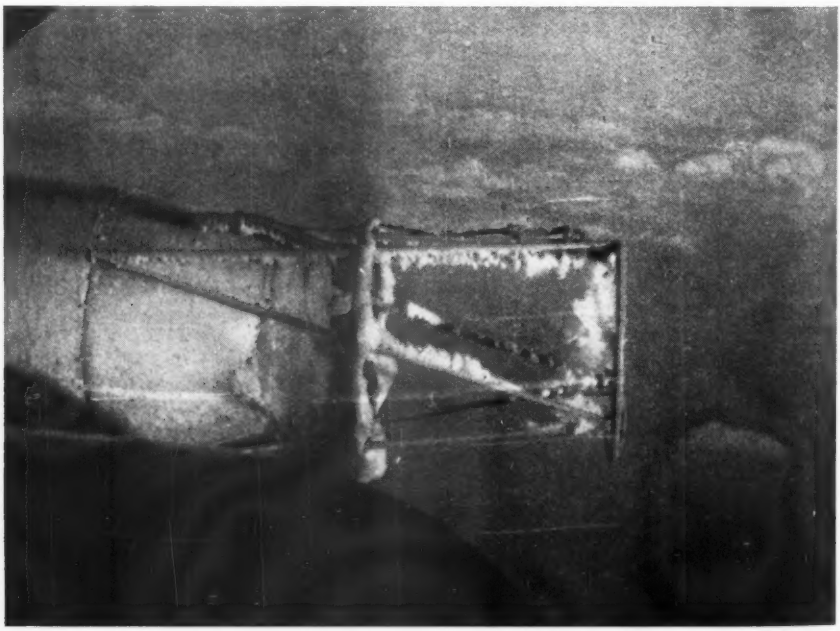


Fig. 38.
Nene icing flight.

Conference in September 1947,* but since then it is of interest to mention that a Lancastrian Nene aircraft (Fig. 21) has done considerable flying in artificially-created icing conditions.

An interesting photograph of icing on a Nene in flight is shown in Fig. 38.

A typical flight record is shown in Fig. 37, from which it will be noted that the 2 gms./cu. metre icing spray had to be turned off after 9½ minutes because of the steadily increasing jet pipe temperature.

The film of another icing flight also provides ample evidence of the icing created.

There are many other problems which could be mentioned, but it is hoped that sufficient has been said to show:—

(*a*) That the achievement of a high degree of reliability has been obtained and is accepted as a major responsibility in power plant design.

(*b*) That in the rare occurrence of power plant fires these can be extinguished without danger to the aircraft.

(*c*) That the noise and vibration problems are now understood and should enable new Civil aircraft to be designed to give a degree of passenger comfort comparable with railway travel.

I wish to thank Rolls-Royce Ltd. and the Ministry of Supply for permission to publish much of the information included in this Paper.

* Aeronautical Conference Volume 1947. Published by the Royal Aeronautical Society.

DISCUSSION

Dr. H. Roxbee Cox (Chairman): Dr. Still had mentioned in connection with exhaust systems that their first proposals were not suitable from the operator's or passengers' point of view. The passenger not only liked to be safe, he liked to feel safe and small things could disturb him. Although he had been flying fairly regularly for 30 years or so, he would not forget his first night flight in a DC-3 in 1938. It was about two o'clock in the morning and from his seat the exhaust manifold on the starboard side looked red hot—rather too hot, so he sat on the other side and looked at the port side manifold; it was dull, and looked quite cool and this lack of symmetry seemed wrong. To reassure himself he told the stewardess that the starboard manifold was very red and asked if it were all right. She replied "Yes." He then pointed out that the one on the other side wasn't nearly so red, to which she replied, "No, it never is!" He would have been happier if they had both looked the same.

Dr. Still remarked that the turbine was still a long way off, but he did not agree. The reciprocating engine was very fully developed and in the past there had been a little too much optimism about the future of the turbine engine. They must try to get a clearer perspective. The obvious truth was that both the piston and turbine engines were here and he could not see either of them being displaced in his life-time. For the highest economy, for economical running of freight, for light aeroplanes, for short trips and for a whole variety of duties they were going to use the piston engine for a long time, but for very high altitudes and high speed purposes, turbines would be needed. The turbine had its problems and it would take a long time to solve many of them, but he felt that there was a sphere of influence for the reciprocating engine, another for the airscrew gas turbine and another for the jet propulsion engine, and that all three would exist for a long time.

N. E. Rowe (British European Airways, Vice-President R.Ae.S., *Fellow*): He was particularly glad to open the discussion for two reasons. First he had known Dr. Still for a long time and had appreciated the refreshing way in which he gave his lecture with little reference to the written paper.

Secondly, this was the first occasion on which the Royal Aeronautical Society had held one of its main lectures in the provinces and for that reason it was a unique and historic event; he hoped it would be the first of many papers read outside London at various centres throughout the country. There were representatives present from Manchester and Yeovil and there was a good contingent from Wolverhampton. Apart from the fact that Birmingham was their President's birthplace, which was a good reason for holding the first of these occasions there, it had also given them an opportunity to give recognition to the admirable work done by the Birmingham Branch.

He had the impression that they tended to go to extremes in their measures of prevention of fire, as a result of the wave of feeling which was aroused after a bad accident. He realised that quick remedial action had to be taken in such cases, but often because it was hurried, the answer in terms of hardware was by no means the best, nor had they necessarily done more than produce a palliative rather than a basic preventive. Hence he suggested in such cases they should have a review of the regulations and designs from time to time to satisfy themselves that a marked improvement was not possible.

He thought the most important thing in regard to fire risk for turbine engines that could be done at this stage was to find out what the risk really was. Had they had any fire in flight in turbine or propeller-turbine engines and what could be done to prevent them? It was far more economical and better for aviation generally, especially for aviation that had to pay its way, to put the fire out, as it were, before it started.

One aspect of the paper in which he was extremely interested, was the development of light alloy radiators. How far had tests been made under conditions of vibration? He thought that although in straight running tests without vibration everything might be all right, the introduction of vibration might possibly show up faults more akin to those likely to occur in actual flight. He was interested that Dr. Still confirmed that tests on a comparatively small scale on radiators were completely borne out in the larger scale of actual flight.

For civil aviation he thought they were likely to make use of the turbine-propeller form sooner than the pure jet. Therefore he was most interested in the icing of turbine-propeller engines and would like to know how far that problem was likely to be readily solved.

G. W. Wilson (Senior Ministry of Supply official at the R.C.A.F. Winter Experimental Establishment, Canada, *Assoc. Fellow*): He thought that it was quite likely that civil aircraft would not be called upon to operate at temperatures of $-50°C$. or lower. It was more than likely that the aircraft would stay on the ground for a short time at refuelling stops where, if it had to remain longer than that period, it would be placed in heated hangars. But there was the possibility that when operating over Arctic regions the aircraft might be forced to land away from sheltered bases, therefore the outside air temperatures on the ground might even be lower than those called for in the regulations, and it would be then that those regulations would be appreciated. He believed that the regulations calling for $-50°C$. had been raised to $-40°C$., because of the known average around the Arctic regions of the world where civil aircraft were likely to operate and at present were being operated in many cases by the American airlines. He would like to correct an impression that the Government Winter Establishment very rarely experienced temperatures below $-40°C$. He had been connected with that organisation for the past five years, and they had, on many occasions, experienced temperatures below $-40°C$. and, in fact, had gone down to $-52°C$.. in spite of not being located in the coldest parts of Canada. Dr. Still had referred to a school of thought, thinking in terms of $-80°C$., and doubted whether that would be experienced. Two years ago, record low in Northern Canada was $-83°C$., but he did not think any aeroplane would be able to operate in that temperature, and even if it could, he did not think the crews could anyway.

He had been very interested in the film which Dr. Still had shown and which, by the way, quoted $-35°C$. That film had been taken at a very early part of the winter season at the main base in Edmonton, which did not enjoy very low temperatures anyway; that was the reason why they had advanced bases up in the Yukon and on the West Coast of the Hudson Bay. They were not the coldest places in Canada, but they used them for special reasons, the main one being lines of communication, which were necessary for experimental work.

Sqdn.-Ldr. E. P. Bridgland, R.C.A.F. (Chief Engineering Officer R.C.A.F. Winter Experimental Establishment, *Assoc. Fellow*): He agreed that $-40°C$ was a reasonable temperature for a civil operator, because in any case before planning a scheduled flight, they would have time to change their programme. This of course did not solve the military problems in which they were chiefly interested.

They still had not reached the stage where they could go out in $-42°C$. on an absolutely cold aircraft and know they could start up again without any difficulty at all. There were two main problems associated with the engine, one was putting the fire out, which

they felt required some development on the prime system, and the other was, as Dr. Still mentioned, the oil system. He did not want to go into the subject unduly, but he would like to say that the manufacturers realised that the oil tank was the most important part of the installation and designed it as such. Until correct steps in power plant installation had been made they were always going to have trouble with it.

He would like to correct one small point. The Winter Experimental Establishment was fundamentally a Canadian organisation, although it did work for the Ministry of Supply.

L. C. Savage (Ministry of Supply): He was particularly interested in the cooling aspects and would like to be associated with Dr. Still's claim on what could be achieved by the adoption of light alloy radiators and oil coolers.

He was firmly convinced that this was a most desirable objective as up to 800 lb. could be saved on four-engined aircraft. This was of the utmost importance to airline operators particularly as, in addition, a higher standard of reliability could be expected than with the standard soldered copper components.

In the not very distant future, he hoped that Service trials of a fairly comprehensive character would be made which, it was hoped, would prove convincing.

Dr. Still and others had commented adversely on official design requirements and regulations. He had known Dr. Still for a good many years and, in his experience, although at the outset Dr. Still might argue against them, in the long run he first achieved them and then formulated more difficult ones for himself!

In defence of the so-called severe requirements he would point out that, in starting anything new of which they had no experience, it was essential to get something down on paper.

Thereafter, when the Dr. Stills of the world got down to it and, by patient research, found the real answers, those officially responsible, in general, were only too glad to accept the teachings of experience and modify the requirements accordingly.

J. Wright (Dunlop Rubber Co. Ltd., *Fellow*): He would like to thank Dr. Still for the way in which for many years he had gone into the many aspects of aviation with which they in the Midlands were particularly concerned. Dr. Still had come close to the Rubber Industry, and on many occasions had been able to help them, with the result that they knew rubber and its applications probably better than they otherwise would. He was referring particularly to the flame-proof and cold temperature aspects of the use of rubber in flexible hose assemblies. Because of the disadvantages of some of rubber's properties they used as little as they possibly could, but the little they did use in aircraft products, they had to know quite a bit about. With the co-operation of Dr. Still, it had been possible to develop pneumatic jacks fitted with rubber seals, which were leak-proof over the temperature range of $-50°C.$ to $+90°C.$

In the written paper, Dr. Still had not dealt nearly so closely as he subsequently did in the film with the de-icing problems of the jet engine.

S. E. Beddall (*Fellow*): Were Hoffman starters any better than electrical motors for starting in severe Arctic conditions, and would a glycol spray into the air intake have any real effect under those icing conditions which they had been shown?

He supported the demand that jet engines should not desert kerosene for petrol as a fuel and hoped that the "petrol being more plentiful than kerosene" excuse would not win. The fire risk could not be over-emphasised and he did not agree that civil aircraft emphasised it too much.

S. C. Redshaw (Boulton Paul Ltd., President of the Birmingham Branch of the Society, *Fellow*): He had gained the impression that the question of radiator support was now entirely solved. This surprised him as aircraft manufacturers were still having trouble with these components. It seemed to him that radiators should be supported by a band passing around the matrix; the unit could then be separated by rubber buffers from a rigid cradle. In the method of support so often used at present, the matrix was slung from its corners with the result that high local loads caused failure near the point of support. He was glad to hear that the light alloy radiator was progressing, as it might help to solve some of the installation problems.

On the question of reliability, he thought perhaps more attention should be paid to some of the accessories, such as fuel gauges, valves and so on, which were a constant source of trouble.

Dr. Still had stated that increasing the number of blades tended to decrease the noise, also that the noise of the propeller turbine was likely to be more severe than that from the reciprocating engine. The Boulton Paul Balliol had flown with turbine engine and three-bladed propeller and with a Merlin engine and a four-bladed propeller. By comparison, the Merlin was by far the noisier type, which was in complete contradiction to Dr. Still's predictions.

He had enjoyed the lecture and was sure that all of them from Birmingham were very pleased that it should have been held there.

R. N. Dorey (Rolls-Royce Ltd., *Fellow*), *contributed*: He felt that the remarks the lecturer had made applied in the main to the functional requirements of the power plant, and perhaps it would be in order for him to mention that power plant development was undertaken by Rolls-Royce in the interests of satisfactory engine operation. Their main concern all the time was to ensure that the engines they manufactured not only performed satisfactorily, but in so doing were given the best possible time as regards installation features that it was possible to incorporate.

The power plant development grew from a desire to understand installation problems and to be in possession of accurate information with which aircraft contractors installing their engines could be advised. From this comparatively humble beginning grew the power plant manufacture and development, of which they had had a rather condensed résumé in the paper. The main directive inspiring the development programme outlined had been, in addition to functional requirements — reliability, the reduction of drag and weight, simplicity in operation, mainly from the pilot's point of view, and ease of unit assembly. By this he meant the quickly detachable power plant.

He would like to ask the lecturer to pass a few remarks on the work that had been done to represent tropical conditions, particularly those of humidity, and also to indicate in a little more detail what was actually taking place to prevent the catastrophic icing which had been shown in full-scale flight on the screen that night.

That part of the lecture dealing with fire was probably considered by most of them to have rather over-emphasised this risk. Personally, when flying, the only thing present in his mind that made him disturbed at all was the possibility of outbreak of fire, and it was with considerable satisfaction that those of them in close touch with the development could realise that a first-class bonfire such as they had seen on the screen could be extinguished before their heartbeats were doubled.

N. G. Bennett (Chief Engineer, Graviner Manufacturing Co. Ltd.) *contributed*: The art of power plant flight fire prevention and extinction had made tremendous advances in the past few years.

He found no evidence in the paper that power plant design was yet influenced by the urgent need for safety in crash. Did not Dr. Still agree that power plant design would benefit considerably by a study of crashworthiness which would undoubtedly affect the disposition in the power plant of potential ignition sources and sources of inflammable liquid leakage?

Several jet and piston engine power plants in current use were so designed that extremely high air flow passed through potential fire zones. Thus it was impossible to provide the recently recommended concentration of fire extinguishing gas in these zones without carrying an alarming weight and bulk of fire extinguishant; sometimes as much as 46 lb. liquid for one zone alone.

The loss of such a weight from payload, quite apart from the great difficulty in finding space for the extinguisher containers, was a heavy penalty to the airframe designer and to the operator.

Was it not possible that an all-round saving would be shown on these particular power plants by resorting to the use of ducts, which would prevent the main air flow from passing through fire zones? Alternatively, would not provision of air shutters show a useful weight saving? The zones themselves were relatively small and, but for the air flow, would not require more than four to six lb. of fire extinguishant.

R. B. Farmer (Royal Aircraft Establishment) *contributed*: In his verbal description of the experimental fire tests on piston engines, Dr. Still erroneously stated that the fire prevention requirements for this type of power plant had been based on "theoretical knowledge." These particular requirements were, in fact, written at the end of some 200 full-scale fire tests in aircraft having both liquid- and air-cooled engines, the conclusions being further confirmed by the results of 3,000 similar fire tests in America.

The requirements were also in agreement with recommendations of the Chief Inspector of Accidents, whose branch had, unfortunately, only too much evidence of accidental fires in flight and on crash.

Dr. Still complained of the regulations calling for metal surface temperatures to be below 175°C. in Zone 1 of gas turbine engines, and argued that piston engines had been operating with surface temperatures of the order of 300°C. around exhaust systems. This was hardly a fair analogy since the spontaneous ignition temperature of kerosene was some 150°C. below that of leaded petrol. Yet, would he deny that there had not been many cases of unexplained fires in piston engines, and that there had not already been cases of fire in Zones 2 and 3 of gas turbine power plant as a result of spontaneous fuel ignition?

It had been implied that it was unnecessary, as part of the pilot's fire fighting drill, to close the cooling air flap and so reduce the air flow through the power plant prior to the release of the extinguishing fluid. It was agreed that the experimental fires were successfully extinguished when these flaps remained open, but the applied slip-stream of approximately 80 m.p.h. could hardly be regarded as truly representative of the air flow in flight. The quantity of extinguishant required was a function of the air flow through the nacelle, thus if fires could be extinguished with the flaps open, it would appear to be sound economy to ensure the closure of ventilating air flaps, and so permit a reduction in weight of extinguishing equipment.

The author had criticised the methods of testing fire resistant pipes, but it must be pointed out that for some considerable time tests on this type of pipe had included both the hose and end fittings, and an alternative means of producing the test flame had been provided to ensure consistency.

Bearing in mind that the rate of fire spread with low volatility fuels was much less than with petrol, and that the crash fire risk was now much more important than the flight fire risk, had the author considered the desirability of adopting low volatility fuels for piston engines?

J. S. Garratt-Reed (Birmingham Branch), *contributed*: In his paper Dr. Still said that in case of fire the pilot should "close the throttle and turn off fuel," etc. Would it not be better in the event of fire in the engine, to shut off the fuel first, then *open* the throttle so as to burn up all the fuel possible inside the engine by emptying the float chamber and the petrol feed pipes?

The late Major Norman made some fire prevention tests in early days at the R.A.E. during which he produced a petrol fire in flight on an S.E.5, and put it out with a device to supply "foam" to strategical spots. The conclusion arrived at was that it was better to leave the throttle open, and a report was drafted to that effect.

So far as he remembered, it was proposed to make the release of foam automatic, in case of a crash on landing, with the object of dealing with the more difficult problem of fires following a crash. There was also an automatic switch which cut off the battery under condition of violent deceleration with the same object in view.

DR. STILL'S REPLY

First he would like to say how pleased he was to be asked to deliver this paper in Birmingham, because a vast amount of the work described in the paper had been done in conjunction with firms located within a 50-mile radius of the City, and he would like to pay public tribute to their assistance.

Dr. H. Roxbee Cox: What he intended to say about the application of the pure jet engine of civil aircraft, was that the jet engine had an immediate military future, the propeller-jet an immediate civil future, and the piston engine a permanent role for low-altitude long-range work.

N. E. Rowe: Mr. Rowe seemed to think they might be over-emphasising the fire aspect of the power plant. Their experience had taught them that this aspect had not been given enough attention in the past, in spite of much useful spade work done at the R.A.E. over many years.

Fires had occurred in jet engines in flight, but experience was still lacking as to how far design should be carried to cater for this case.

On the subject of radiator testing, pressure cycling of the units was done with vibration as part of the type test of every new design of radiator. As a result of the work already done on jet engines, it could already be said that the icing problem was not insuperable.

There were at the moment innumerable anti-icing schemes, and the difficulties of the moment were (1) to spot the winner and (2) to decide on the magnitude of the problem, *i.e.* the amount of ice for which to design.

G. W. Wilson: Mr. Wilson had corrected him about the low temperatures which they had experienced at the Winterisation Establishment, for which he was grateful. His information was taken from the published records of his work but excluded this last winter where, by going farther north, he had found very much more severe weather.

Sqdn.-Ldr. Bridgland: In connection with this work thanks were due to Sqdn. Ldr. Bridgland for his reminder that the Establishment was a Canadian organisation. They were very grateful to them for the facilities they had offered and he trusted that the work would continue for many years, for there was much yet to be learned.

S. E. Beddall: Mr. Beddall asked for a comparison between electrical motor and Hoffman starting. The answer was involved if viewed as a whole.

In both cases oil dilution was necessary, but with this aid the engine turning was not a problem so starts could be made by either method. The bigger item was to keep the engine running and to be able to open up for take-off shortly afterwards.

It was agreed that crash landing fires were serious and in many cases were caused by factors quite apart from the power plant. Since these fires were much more common than those in flight it was suggested that more attention might be directed to the aspect of aircraft design.

Dr. Redshaw: Those particular radiators which were still in trouble had not yet passed their prototype type test. When they had Dr. Redshaw need not worry about the result in flight.

Regarding reliability of accessories he would remind him of that thing called Embodiment Loan.

To give the civil operator a reasonable service reliability and get away from the evils of this system, Rolls-Royce had found it necessary to assume responsibility for the quality of all the accessories used. There might have been some excuse for war-time quality in the labour employed, to-day there was no excuse in either the civil or military fields.

He thought Dr. Redshaw mistook his comments about the relative noise of the turbo-propeller and piston engines.

The piston engine would always be more noisy, but he was trying to give a word of warning that since the turbo-propeller ran under cruising conditions so much nearer to T.O. r.p.m., the propeller noises would be greater than those from the piston engine propeller running at the lower per cent. of T.O. r.p.m.

R. B. Farmer: He thought Mr. Farmer had mistaken his reference which was to jet engines. They were only too aware of the work done by the R.A.E. on the subject of fire. On the other hand, of the 3,000 fires in America, none was on liquid-cooled engines with the result that the C.A.A. asked for special tests in England to clear the DC-4 power plants.

Regarding Mr. Farmer's comment on jet engines and surfaces not exceeding 175°C., surely he had forgotten that both engines used lubricating oil.

He was not yet aware of existing jet engines having been divided into Zones, so where did the fire start!

Again, Mr. Farmer misunderstood the statement about radiator flaps. The important point was that with all flaps open the fire could still be extinguished, and this indicated a good reserve. It was not wise to reduce the quantity on the assumption of the flaps being shut as it was always possible to burn a hole in the cowling.

N. G. Bennett: In reading Mr. Farmer's comments he was almost persuaded that they had been wasting time repeating previous experiments,so it was comforting to have Mr. Bennett's confirmation that progress was being made to reduce the fire risk. But even he apparently thought that they placed all their fuel and oil pipes in as vulnerable a spot as possible. He could assure him that much careful thought had been put into this matter. For instance, they had always kept the exhaust system on top of the engine. Their experience to date had not shown that the fire risk was necessarily reduced by ducting the radiator air flow. They might be persuaded to reduce the quantity of methyl bromide too much on this argument based on the design regulations. On the other hand it was safe to say that all future power plants would use ducted radiators for aerodynamic reasons.

If the fire films had done anything to bring home to all concerned the importance of the fire risk, they had been worth while.

DELAYS IN LANDING OF AIR TRAFFIC*

by

T. PEARCEY, A.R.C.S.

1. INTRODUCTION.

A recent paper[1] gave an elementary analysis of the effect of control procedures on the flow of air traffic. It was shown that the average delay experienced by aircraft landing at an airport increases rapidly as the arrival rate approaches the maximum handling capacity of the airport. It is the object of the present paper to give a more rigorous treatment of the problem and to derive the distribution of delays under different traffic conditions.

The maximum handling capacity of an airport is the greatest rate at which aircraft can enter the airport with absolute safety. It is determined by the *safe minimum separation* between successive landings. An aircraft arriving in the central zone with less than the safe minimum separation is withheld from landing until the minimum interval has elapsed.

In the following it is generally assumed that aircraft cross the boundaries of the control zone from random directions with random separations, the mean arrival rate being constant. Aircraft which follow their predecessors too closely are assumed to be delayed for a minimum period so that none lands with an interval less than the safe minimum. As a simplification it is assumed that no aircraft takes off from the airport.

The effect of the holding procedure on the distribution of the intervals between aircraft landings eliminates intervals less than the safe minimum, and the time taken in operating the holding procedure closes up the longer intervals. No aircraft is speeded up.

In the mathematical analysis the basic unit of time is the mean arrival interval, and all other intervals will be referred to this unit. The basic parameter (T) is the ratio of the safe minimum landing interval to the mean arrival interval, and may be interpreted as the degree of saturation of the airport. The distribution of the arrival intervals t relative to the mean interval follows the distribution for random events. In the following we shall usually refer to both of these variables as "intervals." The probability $P(t)\,dt$ of an interval lying between t and $t+dt$ follows a simple exponential function, *i.e.*

$$P(t)=e^{-t} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

It is clear that no airport can handle a traffic flow which has a mean arrival interval less than the safe minimum separation, so that we shall usually be restricted to cases in which $T<1$. The magnitude of T depends largely upon the time of day and weather conditions, but for simplicity, it is taken as constant for any particular airport.

* Paper received, May 1948.

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NOTATION.

T = ratio of minimum safe landing interval to mean arrival interval.
t = time measured as units of mean arrival interval, and used to specify length of delay.
t_1, t_2, etc. = specific arrival intervals.
n = number of consecutive aircraft all but the first suffering delays.
$\bar{n}$ = average value of n.
$P(t)\,dt$ = probability of an arrival lying between t and $t+dt$.
$p(n)$ = probability of a train of $n-1$ delays.
$A(n)$ = a coefficient occurring in $p(n)$.
m = an integer defining a range of delays t, *e.g.*, the range $mT < t < (m+1)T$. Later extended to non-integral values.
γ = a variable lying between 0 and 1 defining a specific delay t, *e.g.* $t = (m+\gamma)T$.
$Q_T(t)\,dt$ = probability of a delay lying between t and $t+dt$.
$F(m, T)$ = function used to define $Q_T(t)$.

2. THE PROBABILITY OF SUCCESSIVE DELAYS.

As the arriving aircraft land, a certain number will suffer a delay, and there will be occasions when successively arriving aircraft are delayed and form a group of delayed landings between two undelayed landings.

The probability of such a group comprising only one aircraft, *i.e.* the initial undelayed aircraft corresponds to the probability of the following arrival interval being greater than the minimum separation. *i.e.* $t>T$. This probability is

$$\int_T^\infty P(t)\,dt = e^{-T}. \qquad . \quad . \quad . \quad . \quad . \quad (2)$$

Thus, the longer the minimum interval, the smaller is the probability of a single undelayed aircraft being followed by a second undelayed aircraft. This applies even if the minimum interval is greater than the mean arrival interval ($T>1$), so long as the preceding entry is undelayed.

The probability of the occurrence of a group of two aircraft, that is, of one following aircraft only suffering a delay, will be the probability of the following interval t_1 being less than T followed by an interval greater than $(2T-t_1)$, *i.e.*

$$\int_0^T \int_{2T-t_1}^\infty P(t_1)\,P(t)\,dt\,dt_1 = \int_0^T \int_{2T-t_1}^\infty e^{-(t+t_1)}\,dt\,dt_1 = Te^{-2T}. \quad . \quad . \quad (3)$$

The probability of a group of three aircraft will be the probability of the first having an interval $t_1<T$, the second $t_2<2T-t_1$, and the third $t>3T-t_1-t_2$: *i.e.*

$$\int_0^T \int_0^{2T-t_1} \int_{3T-t_1-t_2}^\infty P(t_1)\,P(t_2)\,P(t)dtdt_2dt_1 = \int_0^T \int_0^{2T-t_1} dt_2dt_1e^{-3T} = \left(\frac{3T^2}{2}\right)e^{-3T}. \quad (4)$$

Continuing the process, the probability of n aircraft being successively delayed is therefore equal to

$$\int_0^T \int_0^{2T-t_1} \int_0^{3T-t_1-t_2} \cdots\cdots \int_{(n+1)T-\sum_1^n t_r}^\infty \prod_{r=1}^n [P(t_r)\,dt_r]\,P(t)\,dt$$

$$= e^{-(n+1)T} \int_0^T \int_0^{2T-t_1} \int_0^{3T-t_1-t_2} \cdots\cdots \int_0^{nT-\sum_1^{n-1} t_r} \prod_{r=1}^n dt_r$$

$$= e^{-(n+1)T} \int_0^T \int_0^{2T-t_1} \cdots\cdots \int_0^{(n-1)T-\sum_1^{n-2} t_r} {}^1[nT - \sum_1^{n-1} t_r] \prod_{r=1}^{n-1} dt_r \quad . \qquad (5)$$

The integrations can be performed successively, and the first few expressions for the probablity of limited sequences of delays are

None	delayed		e^{-T}
1	,,		Te^{-2T}
2	,,	$\left(\frac{3}{2}\right)$	T^2e^{-3T}
3	,,	$\left(\frac{8}{3}\right)$	T^3e^{-4T}
5	,,	$\left(\frac{125}{24}\right)$	T^4e^{-5T}
6	,,	$\left(\frac{54}{5}\right)$	T^5e^{-6T}

and so on.

The successive integrations become very cumbersome after the first few of the sequence. We note, however, that in general the probability of $n-1$ aircraft being successively delayed is

$$A(n)\,T^{n-1}e^{-nT} \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where $A(n)$ is a coefficient depending only upon n. Now, since any group of delays must correspond to some value of n, then

$$\sum_{1}^{\infty} A(n)\,T^{n-1}e^{-nT}=1 \quad . \quad . \quad . \quad . \quad . \quad (7)$$

and expansion in power series of T determines the values of $A(n)$. They are the same as those previously listed and satisfy the following recurrence conditions:

$$A(n)=-\sum_{r=1}^{n}(-)^r\frac{(n-r)^r}{r!}A(n-r)$$
$$A(o)=1 \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

For large values of n this method again becomes tedious to use, but a general expression for $A(n)$ can be found. If we write the series as

$$\sum_{1}^{\infty} A(n)\,T^n e^{-nT}=T,$$

it comprises a power series expansion in the variable

$$u=Te^{-T}$$

which, for small values of T, is single valued. We may therefore write

$$\sum_{1}^{\infty} A(n)\,u^n=T(u)$$

and T may be expressed as a power series of u for small values of u; thus

$$T=\sum_{r=1}^{\infty} b_r u^r$$

and by Lagrange's theorem

$$nb_n=\left(\frac{1}{2\pi i}\right)\oint\left(\frac{e^{nT}}{T^n}\right)dt=\frac{1}{n-1!}\left[\frac{d^{n-1}}{dt^{n-1}}\,e^{nT}\right]_{T=0}$$

$$i.e \quad b_n=\frac{n^{n-1}}{n!}$$

Hence

$$A(n)=\frac{n^{n-1}}{n!} \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

which, for large values of n, may be written as

$$A(n)=\left(\frac{e^n}{n\sqrt{2\pi n}}\right)\left[1-\frac{1}{12n}+\frac{1}{288n^2}\ldots\ldots\right] \quad . \quad . \quad (10)$$

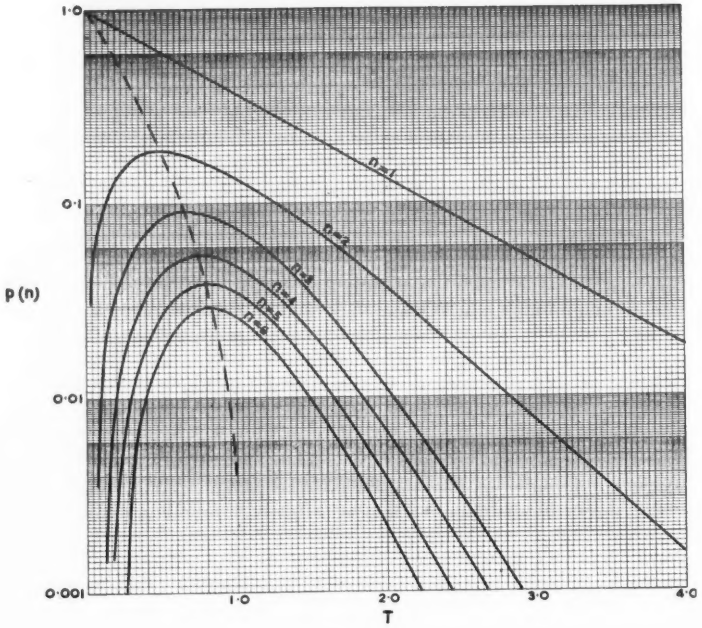


Fig. 1.
Probability $p(n)$ of $(n-1)$ consecutive delays.

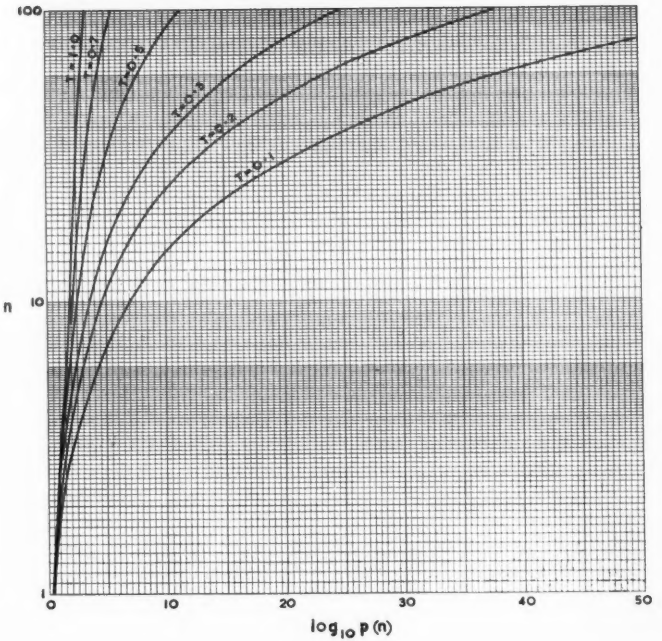


Fig. 2.
Probability $p(n)$ of $(n-1)$ consecutive delays.

The probability of a long series of successive delays affecting $n-1$ aircraft is therefore

$$p(n) = \frac{e^{n[(1-T)+\log_e T]}}{n\sqrt{(2\pi n)}}\left[1 - \frac{1}{12n} \cdot \cdot \cdot \cdot \cdot \cdot\right].$$

It applies for all positive values of T so long as the initial arrival is undelayed. Figs. 1 and 2 show the probability of the occurrence of successive delays, and it will be noticed that each group of delays is most probable for the value of T equal to unity, thereafter decreasing exponentially.

3. THE FRACTION OF AIRCRAFT DELAYED.

A knowledge of the probability of grouping or obtaining a group leads immediately to information about the number of aircraft suffering delays. If $\bar{n}$ is the mean length of a train of delays starting with an undelayed landing, the average fraction of the aircraft delayed is $(\bar{n}-1)/\bar{n}$.

The value of $\bar{n}$ is the first moment of the landing probabilities and can be obtained as follows. We have

$$\sum_1^\infty A(n)\, T^n e^{-nT} = T,$$

so

$$\sum_1^\infty A(n)\left(\frac{d}{dT}\right)(T^n e^{-nT}) = 1,$$

or

$$\frac{\sum_1^\infty A(n)\, nT^n e^{-nT}}{\sum_1^\infty A(n)\, T^n e^{-nT}} = \frac{1}{(1-T)} = \bar{n}.$$

Also

$$\frac{\sum_1^\infty A(n)\, n^2 T^n e^{-nT}}{\sum_1^\infty A(n)\, T^n e^{-nT}} = \frac{1}{(1-T)^3} = \bar{n^2},$$

and so on for higher order moments.

It follows that the fraction of aircraft delayed will be

$$\frac{(\bar{n}-1)}{\bar{n}} = T, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

a remarkably simple result. As would be expected, when the minimum entry interval becomes the same as the mean arrival interval (*i.e.* $T=1$), all aircraft are delayed.

4. THE DISTRIBUTION OF LANDING INTERVALS.

Since the fraction T of arrivals is delayed before entry, it is also the fraction of aircraft which is associated with T as the preceding landing interval. The fraction $(1-T)$ will be preceded by an interval greater than T, and these undelayed arrivals must also satisfy the random distribution. The amount of time during which delaying control is not exercised will be also a fraction $(1-T)$ of the total time.

The distribution of intervals of entry will be

$$\begin{array}{rl} O\,; & O < t \leqslant T \\ T\,; & t = T \\ (1-T)\, e^{-t+T}\,; & t > T \end{array}$$

In terms of the usual discontinuous functions the entry interval distribution may be written as

$$(1-T)\,H(T-t)\,e^{-t+T}+T\delta(T-t)$$

where $H(T-t)$ is the Heaviside step function, and $\delta(T-t)$ the Dirac function.

The distribution of intervals during which the control system is quite free from operation corresponds to the period of the arrival interval greater than T, *i.e.* the probability of a period t to $t+dt$ when control is not operated is

$$(1-T)\,e^{-t}dt.$$

5. THE DISTRIBUTION OF DELAYS.

Of greatest importance is the probability of a delay of a specific amount to which any arriving aircraft is subject.

A knowledge of the nature of the delays can be obtained by considering what happens for small values of T. In this case all the arrivals with interval less than T are held, the delays being $(T-t)$. Those aircraft with small arrival intervals constitute the portion of the total equal to:

$$1-e^{-T}$$

or,

$$T-\frac{T^2}{2!}+\frac{T^3}{3!}-\frac{T^4}{4!}\cdots\cdots$$

But the total fraction delayed is T, so that the fraction

$$\frac{T^2}{2}-\frac{T^3}{6}+\frac{T^4}{24}\cdots\cdots$$

comprises those arriving with intervals greater than T. For small values of T this is small compared with the total delayed, that is, most of the delays come from the small-interval arrivals. The distribution of delays of length t must, therefore be very nearly equal to

$$e^{t}\,;\quad O<t\leqslant T,$$

and

$$O(T^2)\,;\quad t>T$$

which increases with t up to T, and is there discontinuous, falling to a value of the order of T^2.

We may expect, therefore, the distribution of delays for larger values of T to possess discontinuities depending upon T. For a detailed study we return to the analysis of the delaying procedure.

If the first arrival is not delayed, the following will experience a delay of t to $t+dt$ with a probability of

$$e^{-T+t}dt \qquad O<t<T$$

and the probability of a period t to $t+dt$ not subject to any control whatever will be

$$e^{-T-t}dt,\ t>O$$

i.e. the probability that the next arrival occurs at time $T+t$ after the initial arrival.

The probability of the second arrival being delayed is

$$(1-e^{-T}).$$

If the second arrival occurs within T of the first, the third arrival will have the probability of being delayed by t to $t+dt$ given by

$$\int_0^T e^{-t_1-t_2}dt_1dt_2 \quad \text{or} \quad \int_0^{2T-t} e^{-t_1-t_2}dt_1dt_2$$

which, with $t_1+t_2=2T-t$, becomes:

$$Te^{-2T-t}dt \quad \text{for} \quad O<t<T, \text{ where } O<t_1<T$$

$$(2T-t)e^{-2T+t}dt \quad \text{for} \quad T<t<2T, \text{ where } O<t_1<2T$$

The probability of an uncontrolled period of t to $t+dt$ before the third arrival is

$$Te^{-2T-t}dt$$

and of any free period at all

$$Te^{-2T}.$$

The probability of the third arrival being delayed is

$$1-(e^{-T}+Te^{-2T}).$$

Further, if the third arrival is delayed the probability that the next will suffer delay of t to $t+dt$ is, with $t_1+t_2+t_3=3T-t$

$$\int_{0}^{T} dt_1 \int_{0}^{2T-t_1} dt_2\, e^{-t_1-t_2-t_3}dt_3=(3T^2/2)\, e^{-3T+t}dt, \text{ for } O<t<T.$$

and

$$\int_{0}^{T} dt_1 \int_{0}^{3T-t_1-t} dt_2\, e^{-t_1-t_2-t_3}dt_3=\tfrac{1}{2}T\,(5T-2t)\; e^{-3T+t}dt, \text{ for } T<t<2T.$$

$$\int_{0}^{3T-t} dt_1 \int_{0}^{3T-t_1-t} dt_2\, e^{-t_1-t_2-t_3}dt_3=\tfrac{1}{4}\,(3T-t)^2\; e^{-3T+t}dt, \text{ for } 2T<T<3T.$$

The probability of the fourth arrival occurring after a free interval of t to $t+dt$ is

$$(3/2)\,T^2e^{-3T-t}dt$$

and the probability that the fourth arrival is undelayed is

$$(3/2)\,T^2e^{-3T}.$$

The probability of the fourth arrival being delayed at all is

$$1-(e^{-t}+Te^{-2T}+(3/2)\,T^2e^{-3T}).$$

Extending this, if the fifth arrival is delayed it will be subject to the following probabilities

$$e^{-4T+t}\frac{8T^3}{3}\,dt \text{ or } e^{-4T+t}dt\left[\frac{(3T)^3-(3t)^3}{6}-\frac{T^2}{2}\cdot T\right] \text{ for } O<t<T$$

$$e^{-4T+t}dt\frac{T^2}{6}(25T-9t) \text{ or } e^{-4T+t}dt\left[\frac{(4T-t)^3-(3T-t)^3}{2}-\frac{(2T-t)^2}{2}T\right] \text{for } T<t<2T$$

$$e^{-4T+t}dt\,\frac{T}{6}\,(37T^2-21tT+3t^2) \text{ or } e^{-4T+t}dt\left[\frac{(4T-t)^3-(3T-t)^3}{6}\right] \text{ for } 2T<t<3T$$

$$e^{-4T+t}dt\frac{(4T-t)^3}{6} \text{ for } 3T<t<4T$$

The probability of a free interval of t to $t+dt$ before the fifth arrival is

$$(8/3)T^3e^{-4T-t}dt$$

and the probability of the fifth arrival being delayed is

$$1-\sum_{1}^{4} A\,(n)T^{n-1}e^{-nT}.$$

From the next we notice a definable relationship for prediction of the remainder of the distribution of delays. The probability of a delay t to $t+dt$ for the sixth arrival, if the fifth is delayed, is

$$e^{-5T+t}dt\,\frac{135}{24}\,T^4, \text{ or } \left[\frac{(4T)^4-(3T)^4}{4!}-\frac{(2T)^2}{3!}\,T-\frac{T^2}{2!}\cdot\frac{3T^2}{2}\right]e^{-5T+t}dt. \text{ for } O<t<T$$

$$e^{-5T+t}dt\left[\frac{(5T-t)^4-(4T-t)^4}{4!}-\frac{(3T-t)^3}{3!}\,T-\frac{(2T-t)^2}{2!}\,\frac{3T^2}{2}\right] \text{ for } T<t<2T$$

$$e^{-5T+t}dt\left[\frac{(5T-t)^4-(4T-t)^4}{4!}-\frac{(3T-t)^3}{3!}\,T\right] \text{ for } 2T<t<3T$$

$$e^{-5T+t}dt\left[\frac{(5T-t)^4-(4T-t)^4}{4!}\right] \text{ for } 3T<t<4T$$

$$e^{-5T+t}dt\,\frac{(5T-t)^4}{4!} \text{ for } 4T<t<5T$$

The total probability of the sixth arrival being delayed at all, is

$$1 - \sum_{1}^{5} A(n)\, T^{n-1} e^{-nT}.$$

In general then, if the $m+1$th arrival is delayed it will be subject to the probabilities

$$e^{-mT+t}dt \left[\frac{((m-1)T)^{m-1} - ((m-2)T)^{m-1}}{m-1!} A(1) - \frac{((m-3)T)^{m-2}}{m-2!} A(2) \right.$$

$$\left. - \frac{((m-4)T)^{m-3}}{m-3!} A(3) \ldots - \frac{T}{2!} A(m-2) \right] = e^{-mT+t} A(m) T^{m-1} dt, \text{ for } O < t < T$$

$$e^{-mT+t}dt \left[\frac{\{(mT-t)\}^{m-1} - \{(m-1)T-t\}^{m-1}}{m-1!} A(1) - \frac{\{(m-2)T-t\}^{m-2}}{m-2!} A(2) \right.$$

$$\left. - \frac{((m-3)T-t)^{m-3}}{m-3!} A(3) \ldots - \frac{(2T-t)^2}{2!} A(m-2) \right] \text{for } T < t < 2T$$

$$e^{-mT+t}dt \left[\frac{(mT-t)^{m-1} - ((m-1)T-t)^{m-1}}{m-1!} A(1) - \frac{((m-2)T-t)^{m-2}}{m-2!} A(2) \ldots \right.$$

$$\left. - \frac{(3T-t)^3}{3!} A(m-3) \right] \text{for } 2T < t < 3T$$

with m such sequences, the last being

$$e^{-mT+t}dt \frac{(mT-t)^{m-1}}{m-1!} \text{ for } (m-1)T < t < mT.$$

We can now construct the complete expressions for the delays. The fraction of aircraft not delayed is $1-T$; the fraction

$$(1-T)(1-e^{-T})$$

can experience delays from O to T; while the fraction

$$(1-T)\{1 - e^{-T} - (3T/2)e^{-2T}\}$$

can experience delays from O to $2T$, and so on. Compiling the various sets capable of experiencing the same range of delays we find the fraction of the whole capable of experiencing a delay t to $t+dt$ between O and T to be

$$(1-T)e^{+t}\left[dte^{-T} + Te^{-2T} + \frac{3T}{2} e^{-3T} \ldots \right] = (1-T)e^{+t}dt, \qquad O < t < T,$$

for the range T to $2T$ the fraction:

$$(1-T)e^{+t}dt \left\{ (2T-t)e^{-2T} + \left[\frac{(3T-t)^2 - (2T-t)^2}{2!} \right] e^{-3T} + \left[\frac{(4T-t)^3 - (3T-t)^3}{3!} \right. \right.$$

$$\left. - \frac{(3T-t)^2}{2!} T \right] e^{-4T} \ldots + \left[\frac{(mT-t)^{m-1} - ((m-1)T-t)^{m-1}}{m-1!} \right.$$

$$\left. \left. - \frac{((m-2)T-t)^{m-2}T}{m-2!} A(2) \ldots - T^{m-3} \frac{(2T-t)^2}{2!} A(m-2) \right] e^{-mT} \right\}, T < t < 2T.$$

for the range $2T$ to $3T$ the fraction:

$$(1-T)e^{+t}dt \left\{ \frac{(3T-t)}{2!} e^{-3T} + \frac{(4T-t)^3 - (3T-t)^3}{3!} e^{-4T} + \left[\frac{(5T-t)^4 - (4T-t)^4}{4!} \right. \right.$$

$$\left. - \frac{(3T-t)^3}{3!} T \right] e^{-5T} \ldots + \left[\frac{(mT-t)^{m-1} - ((m-1)T-t)^{m-1}}{m-1!} \right.$$

$$\left. \left. \frac{((m-2)T-t)^{m-2}T}{m-2!} A(2) \ldots - T^{m-3} \frac{(3T-t)^3}{3!} A(m-3) \right] e^{-mT} \right\}, 2T < t < 3T,$$

for the range $3T$ to $4T$:

$$(1-T)\,e^{+t}dt\left\{\frac{(4T-t)^3}{3!}\,e^{-4T}+\frac{(5T-t)^4-(4T-t)^4}{4!}\,e^{-5T}\ \ldots\right\}\quad,\quad 3T<t<4T,$$

and so on. If we collect terms together we find that the probability of a delay t lying between mT and $(m+1)T$ is

$$(1-T)\,e^{+(t-T)}dt\left\{\sum_{r=0}^{\infty}\frac{((m+r+1)T-t)^{m+r}}{m+r!}\,e^{-(m+r)T}\right.$$

$$\left.-\sum_{r=0}^{\infty}\frac{((m+r+1)T-t)^{m+r+1}}{m+r+1!}\,e^{-(m+r)T}\left[\sum_{n=1}^{\infty}T^{n-1}A(n)\,e^{-nT}\right]\right\}$$

or

$$(1-T)\,e^{+(t-T)}dt\sum_{r=0}^{\infty}\frac{((m+r+1)T-t)^{m+r}}{m+r+1!}\,[t+(m+r+1)(1-T)]\,e^{-(m+r)T}$$

$$\text{for } mT<t<(m+1)T. \qquad . \qquad (12)$$

This we write as $Q_T(t)\,dt$.

If we put t equal to $mT+\gamma T$, where γ ranges from zero to unity, then the above expression for the probability of a delay $(m+\gamma)T$ becomes

$$TQ_T(\gamma T)d\gamma=(1-T)\,e^{-(1-\gamma)T}T^{m+1}d\gamma\sum_{r=0}^{\infty}\frac{(r+1-\gamma)^{m+r}}{m+r!}\,T^re^{-rT}\left[1-\frac{(r+1-\gamma)T}{m+r+1}\right]$$

while for $m=0$, the probability is $T(1-T)\,e^{\gamma T}d\gamma$.

That this expression corresponds to the time distribution of delays, may be checked by finding the total number of aircraft delayed. Upon integration of (12) over the whole range of delays, then

$$\sum_{0}^{\infty}Q_T(t)dt=(1-T)\left\{\int_0^T e^{-t}dt+\sum_{m=1}^{\infty}\sum_{r=0}^{\infty}\int_{mT}^{(m+1)T}e^{t-(m+r+1)T}\cdot\right.$$

$$\left.\cdot\left(\frac{(m+r+1)T-t}{m+r+1!}\right)^{m+r}[t-(m+r+1)(1-T)]\,dt\right\}=T \qquad . \qquad . \qquad (13)$$

as required. The fraction of aircraft delayed is T.

From (12) it is easy to derive the mean delay by multiplication by t, and integration. From such a process we find the mean delay of all aircraft to be

$$\tfrac{1}{2}T^2/(1-T)\ . \qquad . \qquad . \qquad . \qquad . \qquad . \qquad (14)$$

a function which increases quadratically for small rates of arrival (small T), and is therefore small, but becomes large at large rates of arrival. The results expressed in (13) and (14) correspond to those stated in a previous paper.[1]

6. THE PROPERTIES OF THE DELAY DISTRIBUTION.

From (12) we find the distribution of delays to possess a discontinuity only at the value of t equal to T, for if t approaches $(m+1)T$ from the lower side we obtain the limiting probability with γ equal to unity.

$$T^{m+1}dt\sum_{r=0}^{\infty}\frac{r^{m+r}}{m+r!}\,T^re^{-rT}\left[1-\frac{rT}{m+r+1}\right]$$

of which the first term is zero. If, however, t approaches $(m+1)T$ from the upper side we obtain, putting $(m+1)$ in place of m and allowing γ to become zero, the identical series:

$$T^{m+1}dt\sum_{r=0}^{\infty}\frac{(r+1)^{m+r+1}}{m+r+1!}\,T^{r+1}e^{-(r+1)T}\left[1-\frac{(r+1)T}{m+r+2}\right].$$

For $t>T$ the distribution of delay is continuous and also has continuous derivatives, for the series possesses only those factors containing r, namely $(r+1-\gamma)$ and $(m+r)$.

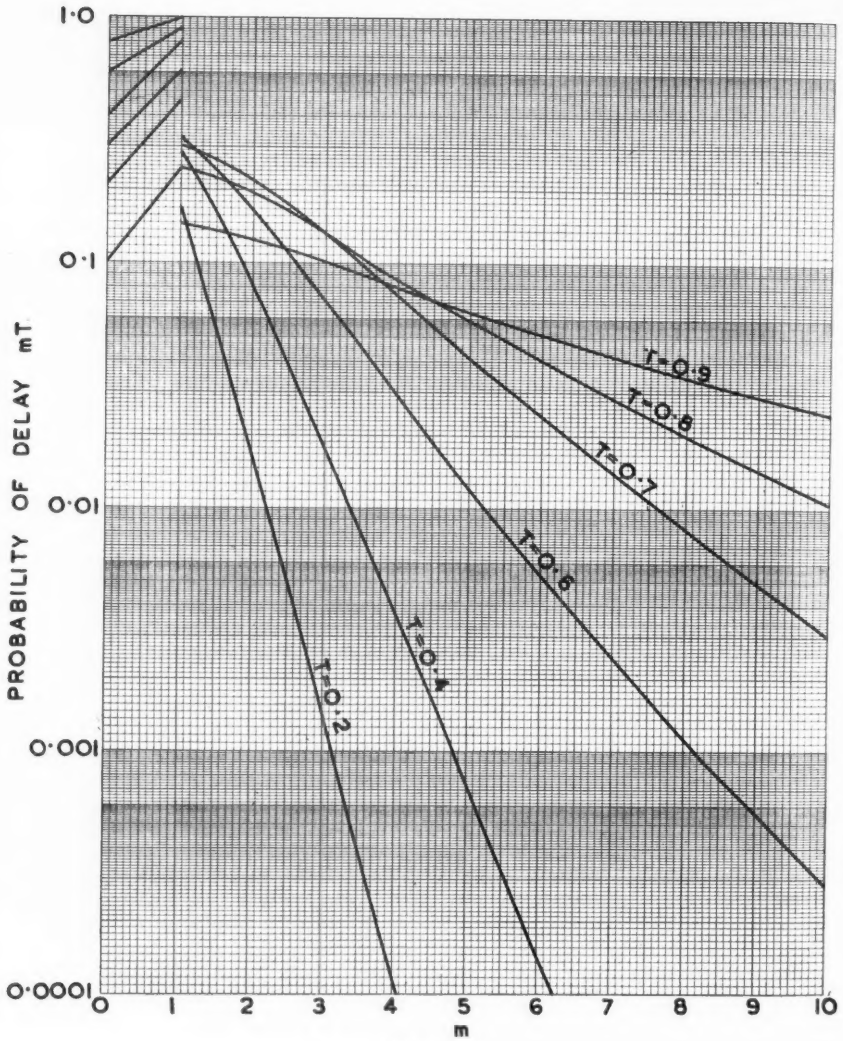


Fig. 3.
Probability of a delay (mT).

The expression (12) can be reduced for computing purposes: for, if we put γ equal to unity and write

$$\pi(m, r) = \frac{r^{m+r}}{m+r!}$$

and

$$F(m, r) = T^m \sum_{r=0}^{\infty} \pi(m, r)(Te^{-T})^r$$

then (12) becomes:

$$Q_T(mT) = (1-T)[F(m, T) - F(m+1, T)].$$

The summation may be extended to some value p of r for which $p>>m$, and the remainder of the series may be approximated to an integral: *i.e.*

$$F(m, T) \doteqdot T^m \sum_{r=0}^{p} \pi(m, r)(Te^{-T})^r + \frac{e^{-m(1-T)}}{\sqrt{2\pi(T-1-\log_e T)}} \int_{(p+1)(T-1-\log T)}^{\infty} e^{-x} x^{-\frac{1}{2}} dx$$

The integral corresponds to the incomplete Γ-function which has been tabulated by Pearson. Values of the probability are thus obtained for integral values of m.

If T is small the probability of a delay $(m+\gamma)T$ decreases very rapidly for it is approximately equal to

$$e^{-(1-\gamma)T} \frac{(1-\gamma)^m \Gamma^m}{m!}$$

but as T increases there is a strong tendency for long delays to become more probable. Eventually when T is near unity, the decrease with length of delay is small. This is illustrated in Figs. 3 and 4 where the delays are illustrated on two different scales. Fig. 4 also contains on the left-hand side the corresponding curves of the control-free intervals. The discontinuity at T, illustrated in these figures, is equal to

$$(1-T)(e^T - 1).$$

The series (12) is difficult to compute when both T and m are large, for the convergence is slow. We may overcome this difficulty in the case in which m is sufficiently great by converting the series into an integral. Thus we may write approximately

$$F(m, T) = \frac{e^{mT}}{2\pi} \int_0^{\infty} \left(\frac{r}{m+r}\right)^{m+r} . \exp.[-(m+r)(T-1-\log_e T)]\, dm$$

By replacing $1-(m/m+r)$ by t we find instead

$$F(m, T) = e^{mT} \sqrt{\frac{m}{2\pi}} \int_0^{\infty} (1-t)^{-\frac{3}{2}} \exp.[-m(x-\log_e t)/(1-t)]\, dt$$

where $x = T - 1 - \log_e T$ and is always positive.

Now, we have stipulated that m shall be sufficiently large so that the integral may be evaluated approximately by "steepest descents." The exponent possesses a col at the value t_o, which depends only on x, and is the solution of the transcendental equation

$$x = \log_e t_o - 1 + t_o^{-1}$$

The integral now becomes

$$F(m, T) = \frac{e^{m(Tt_o-1)/t_o}}{\sqrt{\pi}} \frac{t_o}{(1-t_o)} \int_{-\infty}^{+\infty} e^{-\tau^2} d\tau = \frac{t_o}{1-t_o} e^{m(Tt_o-1)/t_o}, \text{ and } 1 \geqslant Tt_o.$$

The probability of a delay in the neighbourhood of mT is, therefore, given by

$$Q_T(mT) = \frac{t_o(1-T)}{(1-t_o)} e^{-m(1-Tt_o)/t_o}[1 - e^{-(1-Tt_o)/t_o}] \quad . \quad . \quad (15)$$

so long as m is sufficiently great and T is not too close to unity. The extended curves of the delay distribution are illustrated in Fig. 5. As T tends to unity t_oT tends to unity also; the value of Q still retains an exponential character in m.

It will be noticed from Figs. 3 and 5 that the probability of a delay of mT is never larger than $0.35m$, no matter what the value of T. This may be taken as a criterion describing the worst possible conditions of congestion for any airport. Thus

$$Q_T(t) \text{ not greater than } \frac{0.35T}{t} \quad . \quad . \quad . \quad . \quad (16)$$

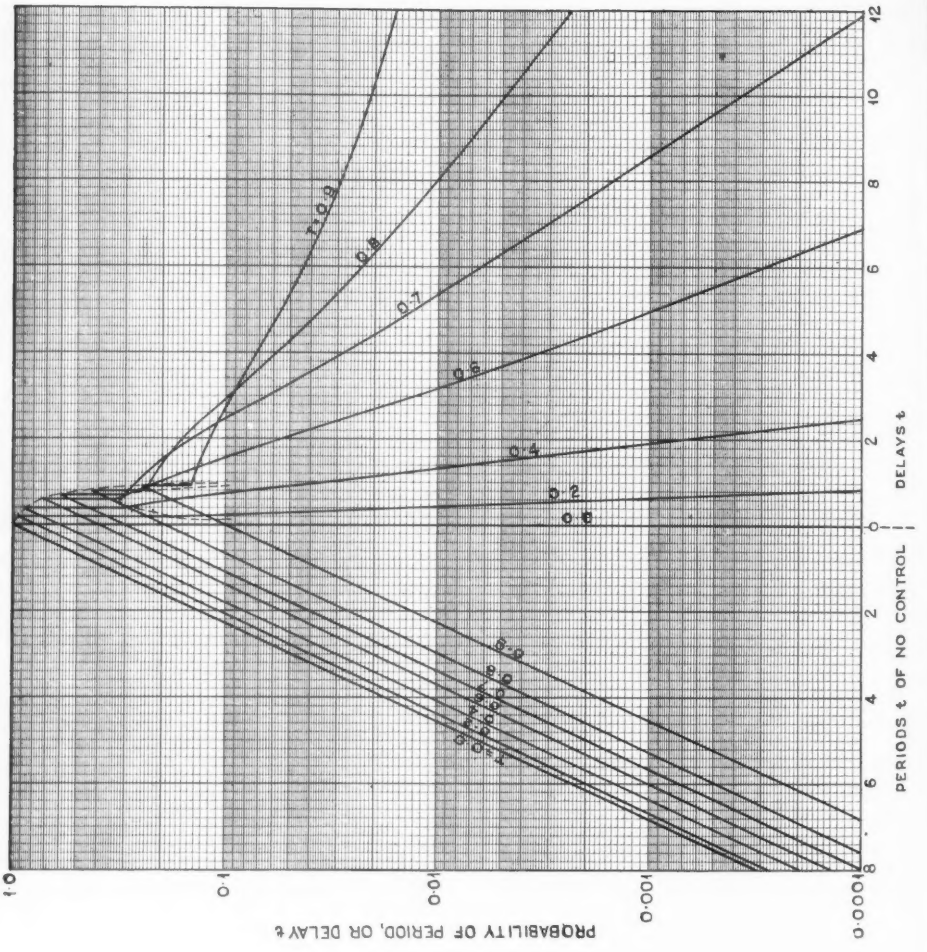


Fig. 4.
Probability of delays and free intervals of length t.

7. CONCLUSION.

The probability that any particular aircraft suffers a controlled delay before landing at an airport is, in the case of randomly arriving traffic, proportional to the degree of saturation (T) of the airport, that is, to the ratio of the minimum safe landing interval to the mean arrival interval (see equation 11).

However, the average delay for small degrees of saturation ($T<<1$) is quite small but increases rapidly with increasing degrees of saturation. In fact the average delay is equal to the mean arrival interval for a degree of saturation equal to 0.75 (*cf.* expression 14).

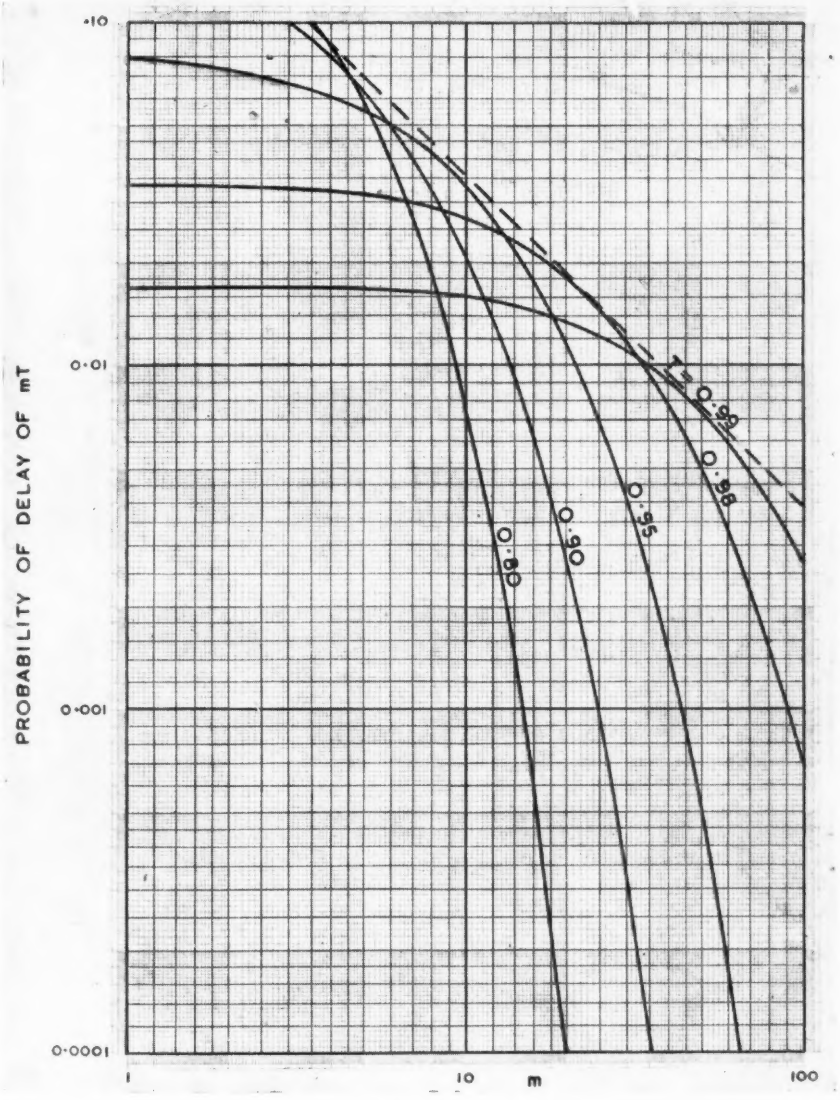


Fig. 5.
Probability of long delays near saturation conditions.

The probability of delay first increases up to the delay equal to the minimum separation, beyond which point it suddenly falls to a smaller figure and thereafter continues to decrease (*cf.* Fig. 3). For small degrees of saturation, the probability of delay greater than the minimum separation falls to very small amounts, but the rate of decrease of the probability of delay with increasing delay becomes very slow for high degrees of saturation (*cf.* Figs. 4 and 5). An upper limit has been deduced

for the probability of a long delay which may prove useful in practice (*cf.* expression 16).

It appears that a true estimate of the necessary handling capacity of an airport can be obtained only from a criterion based upon knowledge of distribution of delays. It is not sufficient to base the estimate for size only upon the allowable fraction of aircraft delayed and the average delay. A more important criterion would be that only a certain small fraction of aircraft should suffer delays greater than a specified figure.

8. ACKNOWLEDGMENTS.

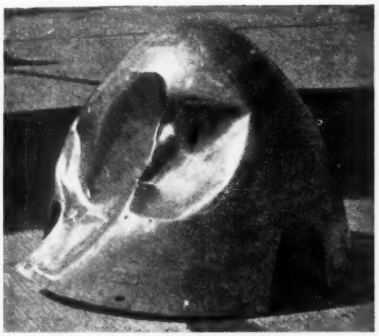
This work was done as part of the research programme of the Radiophysics Division, Council for Scientific and Industrial Research, Commonwealth of Australia. The author wishes to express his indebtedness to Dr. E. G. Bowen for his interest and stimulus during the course of the work.

REFERENCE.

1. Bowen, E. G. and Pearcey, T. "Delays in Air Traffic Flow," J. Roy. Aero. Soc., April 1948.

CORRESPONDENCE

A BIRD "STRIKE"



(Birds crashing into aeroplanes are fairly frequent and well-known incidents, but precise details of such occurrences are unusual. Because of this, the accompanying photograph and information are particularly interesting. They have been contributed by an Associate of the Society, Mr. J. J. V. Flavin.—ED.)

This particular incident occurred when a Lancastrian was entering the landing circuit at Santa Cruz airport, Bombay, one forenoon early in January 1948. The Lancastrian was flying at 1,500 ft. above the airport level, approximately three to five miles from the airport, at an indicated air speed of 140 knots (approx. 161 m.p.h.). At the time there was little cloud; approximately two-tenths maximum.

A number of Bromley Kite Hawks were in the vicinity. These birds, one of the scavengers of India, have a wing tip spread of some three to four feet and are usually to be found round and about any populated area, although Bombay and Calcutta are noted for having rather more than the average population of them. The bird which struck the Lancastrian was first seen by the Captain and Engineer Officer a second, or at most a second and a half, before the impact, when it was above and ahead of the centre line of the aircraft. It seemed to appear from nowhere and gave the impression of diving into No. 2 spinner of the Lancastrian.

No vibration was set up in the engine after the "strike" and the spinner did not appear to be as damaged as the photograph shows that it actually was. As a precaution, revs. were reduced to approximately 1,800 at crankshaft, 756 r.p.m. airscrews, crankshaft to airscrew ratio 1 : 42.

Later examination on the aerodrome showed that there were no marks or bloodstains on any part of the aircraft and all that appeared to be left of the bird was a pulpy mass inside the spinner, spread about the aft half and, in places, a quarter of an inch thick.

MAINTENANCE DESIGN QUESTIONS

Lt. Bowden's questions on Maintenance Design (August 1948 JOURNAL) covered briefly an excellent and representative number of questions which all too frequently plague maintenance personnel. Two additional questions which give further support to some of those already made are:—

1. *Has adequate attention been paid to the general ground handling of the aircraft? What type of towing dollie or bar is recommended? In man-handling a small aircraft, are there certain portions which should be particularly watched in order to prevent damage?*

The problem of pulling an aircraft around the manufacturers' flat concrete apron by means of a light nose or tail wheel towing bar is one thing, but when you are in a hurry and have to get it out of snow or mud practically up to its axles, it is an

entirely different matter. Many aircraft do not possess adequate pick-up points on the main wheels and damage caused by over-stressing can easily occur when pulling up on the tail wheel. Most manufacturers seem to leave this problem to the operator.

2. *Assume a light or a medium-sized aircraft which is used primarily for training; can the wing tips, if damaged, be readily repaired or replaced?*

This may appear to be a small point, but the time spent on wing tip repairs at some training establishments is frequently high. Ground loops, taxi-ing accidents, and ground handling accidents, all contribute. A wing tip which may be replaced quickly and the damaged one sent to the shops saves not only time but distributes the work more evenly.

Lt. Bowden's question No. 5 may appear amusing to a designer, but it is a problem. Not only tools belonging to maintenance personnel may find their way into strange places; aircraft are sometimes received from the builder complete with wrenches, newspapers, and lunch boxes stowed in an unorthodox manner. Passengers and air crew also can shed a variety of gear in an aircraft; navigators are particularly adept at this.

Ques. 6. Ample space, light and drainage should be taken into consideration in all re-filling locations. As Lt. Bowden stated, awkward installations are both wasteful and dangerous, and the whole situation is often aggravated if you have to grope around the inside of a wheel well. In most cases would it not be possible to fit a splash shield or tray around the fluid inlet and have the tray adequately drained? The whole could then be covered with a panel which closed flush to the outside skin.

W. B. F. Mackay, A.R.Ae.S. (Wing Commander, R.C.A.F. Res.,
School of Mines and Metallurgy, University of Minnesota.)

AIRCRAFT ACCIDENTS

The correspondence published in the September issue of the R.Ae.S. JOURNAL concerning aircraft accidents was most interesting, but to my mind somewhat one-sided.

The aeroplane itself is only one factor in the chain of events leading up to an accident. Any manager of an international airport can relate cases of accidents and near accidents because of defective radio communications, unreliable weather reports and so on.

It seems that at present designers, airport managers, operations officers, crews, Government departments and so on do not know enough about the events leading up to accidents, and in this connection nothing less than a world-wide accident organisation can do much good.

It was realised early in the war that a unique opportunity existed to gather a large body of evidence on accidents, and by 1944 the Air Ministry had about 30 officers engaged in full-time accident investigation and analysis. In addition, trained investigators were stationed at Group H.Q.s, and with Naval units, and units of the Dominion Air Forces. Some were specialists in accidents involving fire in the air.

It would be interesting to know whether any analyses of the thousands of cases investigated have been passed to other Governments and to aircraft designers. Perhaps it may not be to the public interest to publish too much, but surely some information could be released.

As far as I know, the U.S.N. and the U.S.A.A.F. did not investigate accidents, at least in operational areas, which was a pity as much valuable information was undoubtedly lost. Since the war, the Civil Aeronautics Administration in the U.S.A. has been supplying their accident reports and analyses freely to foreign Governments and they prove most useful.

Aircraft designers can help, but until they can design aeroplanes on the lines suggested by W/Cdr. J. Carroll, A.F.R.Ae.S., using non-inflammable fuels, the best they can do is to mitigate the worst effects of a crash after it has happened.

Even this little will be difficult, in the face of the steady demand for more payload. Airline operators will always judge an aircraft by its earning capacity, they have to in this fiercely competitive world, and more safety means more weight and less profits.

Thus it is easy to foresee certain nations gaining all the traffic on the international routes if their safety laws are lax. The introduction of two sets of safety requirements for scheduled and non-scheduled airlines in the U.S.A. has proved this.

As usual the lower standard ousted the higher standard, resulting in an epidemic of crashes, and now there is much hardship among airline operators, as American public opinion is insisting, and rightly so, on one standard only.

At present aviation laws, particularly the safety laws, are obsolete and incomplete in many countries and enforcement is inadequate. To cite an example, about the only navigational aid in this part of the world is the radio beacon. It is vital for night flying and in monsoon and dust storm weather. There is no law compelling airline operators to install and keep serviceable the radio range equipment in their aircraft.

At the present stage of development, international unification of flight procedures, better weather forecasting, and international safety standards appear to me to offer the best chances of increasing public safety for some time to come.

It is a herculean task, whatever the approach, but the first step is the formation of an international organisation to see that vital information reaches the people who can use it.

The greatest asset of every nation is its citizens, and every bad crash seems to result in the loss of the most valuable ones. The disruption of business and Government following on the loss of life in crashes is often greater than is generally realised. Safety measures are cheap in money and effort compared with such losses.

W. T. Reid, A.I.N.A., A.R.Ae.S., Karachi Airport, Pakistan.

AIRCRAFT MAINTENANCE

The correspondence on maintenance has overlooked one important feature, namely, the initial training of the design draughtsman.

Whereas an apprentice to marine engineering spends most of his time in the shops doing practical work, the reverse applies to the aircraft apprentice. The result is that the latter has had little chance to do any practical work of consequence.

He has no practical knowledge of mouldings or castings and when given a component to draw, blindly follows someone else who has drawn a similar job.

Drawings are frequently checked only half-heartedly, and are altered to suit the whim of the Section Leader without consulting the man on the job. Another fact to bear in mind has been the admittance (during the War period) into drawing offices of men with little or no drawing office training; this is particularly noticeable in the Aircraft Industry.

The practice of peaning over bolt heads mentioned in Mr. Bevis's letter (October 1948 JOURNAL) is more than "annoying," it is bad engineering practice and should be prohibited by the Air Ministry and "castellated" nuts with split pins or wire substituted.

T. J. McTear, A.R.Ae.S.

It seems the question of "designing for maintenance" is largely an economic one. The original design, while executed with maintenance requirements in mind, will inevitably not be the optimum. How can a nearer approach to the optimum be achieved and how much will it cost?

First, there is the method favoured by some of the correspondents in the October JOURNAL of relying on drawing inspection at the design stage by experienced "chiefs." The cost of this method is in increased wages to more skilled draughtsmen, and in time delay, with possible loss of market, decrease in total number sold and hence increased cost per unit.

Second, one can postulate protracted maintenance trials on the prototype, the cost being composed of that of making the trial and of modifying subsequent production aircraft, and the time delay.

Finally, a "maintenance mock-up" could be built. No manufacturer would consider trying to build even a fighter without an elaborate mock-up of the pilot's cockpit, or trying to sell any commercial type without a mock-up of the passenger cabin. Why then should the mock-up not be made more elaborate and used for maintenance trials? The advantages over the use of the prototype are that the trials can be done at an earlier stage of the design and, at least on paper, it should then be easier and cheaper to incorporate modifications.

I am not qualified to discuss the relative merits of these three techniques, but I would like to see such a discussion from design and production people. My experience in the operations field suggests that sufficient use, in the past, has not been made of the mock-up technique.

But let us turn now to the "Masefields" of the subject. I assume that the manufacturer spends £100,000 improving the maintenance qualities of his product, on which he hopes to recover this cost spread over the first 100 sales. The cost per unit is thus increased by £1,000. The operator's return for this increased outlay lies in decreased maintenance costs, composed of a longer between-overhaul period, and lower man-hours per maintenance item. He may have to pay a penalty in a heavier structure, with decreased payload.

The operator will view the proposition something like this. Assuming revenue payload is worth 0.03 pence/pound/mile, and that the aircraft has a utilisation of 3,000/hours/annum at a block speed of 200 m.p.h., and achieves a payload factor of 0.66, then the potential earning value of payload capacity is $0.03 \times 3{,}000 \times 200 \times 0.66$ pence/pound/annum. £50.

Labour costs 10/- per man-hour, including overhead. On a daily maintenance task, one man-minute/day = 6 man-hours/annum, worth £3 per annum. On a weekly maintenance task, one man-hour/week = 52 man-hours/annum, worth £26. On engine change (assumed at 750 hours) one man-hour/change = 4 man-hours/annum, worth £2.

Money can be borrowed at 4 per cent. per annum. Thus an additional £1,000 on the cost of the aircraft must show a return of at least £40 per annum.

Thus one ounce built into the aeroplane to facilitate maintenance must show a saving of one man-minute on a daily maintenance job, 7 man-minutes on a weekly job, 90 man-minutes on an engine change. And the cost of £1,000 per aircraft spent on improved maintenance is covered by a saving of 80 man-hours/annum in maintenance time, provided no increase in structure weight is involved.

Such over-simplification of the problem gives an incorrect answer, but I hope not a misleading one.

My second point arises from remarks by Watson in the October JOURNAL, and by Halland in the November issue, on the subject of typical repair schemes. My experience is that fitters are skilled at, and accustomed to, translating drawings which are prepared in the orthodox manner and are capable of only one interpretation. Too frequently typical repair schemes consist of out-of-scale freehand sketches and odd stress notes and calculations that only confuse the tradesman. They are, and purport to be, for the operator's drawing office, where a qualified draughtsman examines the damaged part and, using the typical repair as a model, prepares a sketch of the repair to be executed in his case. The subtleties of design and construction techniques of modern stressed-skin aeroplanes are too great to be

left in their repair to the average tradesman. A further objection to the use of a manual, from the tradesman's point of view, is that there are never enough to go round, and he is obliged to prepare his own sketch from which to work. Sketches made in the operator's own drawing office are available in adequate numbers and are consumable, great attractions to the tradesman.

T. F. C. Lawrence, A.F.R.Ae.S.

ECONOMIC FACTORS IN CIVIL AVIATION

The following comments are made on the paper "Some Economic Factors in Civil Aviation" by P. G. Masefield in the October 1948 JOURNAL.

Safety

The author quoted some comparative figures for accident and passenger fatalities which were given recently by a leading American assurance expert, and which seemed to prove that travel by scheduled airline was only about eight times as dangerous as travel by passenger train, and was in fact considerably less dangerous than travel by car or taxi. Do we all accept the fatalities per passenger mile as our yardstick? It is a reasonable basis of comparison for a person who must travel the same distance each year whether he travels by air or by rail—and it gives a figure which unduly favours the airline because of the speed factor.

The average member of the public is not interested in knowing how far he can expect to travel before he meets with sudden death. He is more concerned with his expectation of life in years than in miles, and so are the life assurance companies. If Mr. Lederer's statistics are converted into fatalities per passenger hour, taking present average speeds as 20 m.p.h., 40 m.p.h., 180 m.p.h., and 30 m.p.h. (which are mere guesses on my part, but are probably not far out), the following results are obtained:—

Omnibuses	3.8	deaths	per	100×10^6	passenger	miles.		
Passenger trains	8.4	„	„	„	„	„	„	„
Scheduled airlines	306.0	„	„	„	„	„	„	„
Motor cars and taxis	81.0	„	„	„	„	„	„	„

Accepting the fact that we are more concerned with the length of time for which we may reasonably expect to live than we are with the distance we may reasonably expect to travel before we die, I maintain that the passenger-hour figure is the one in which we are really interested (and the above figures speak for themselves). The life assurance companies appear to hold a similar view, for they do not allow cover at normal rates to air passengers who do not pay their own fares, because such passengers are liable to spend more time flying, and time spent flying has been proved to be extremely dangerous compared with time spent in a train.

Mr. Masefield rightly emphasised the present fire risk with air transport. It is because of this fire risk that large numbers of people, who would otherwise accept the accident risk, are deterred from flying; they not unnaturally refuse to accept the hazard of being roasted alive in a particularly horrible manner. Many of the prospective customers saw the burned-up remains of crashed military aircraft during the last war and, having seen, they are not likely to forget in a hurry. In a rail crash, it is unusual for a large percentage of the hundreds of passengers involved to be killed or even very seriously injured, and the scene which follows the crash does not seem quite so terrible as does that burning fiery furnace and black smoke pall which is inseparably linked in their minds with the average air crash. The fire menace must be conquered if air transport is ever to become popular with the masses.

Will rail transport standards of safety ever be possible for air transport? Surely, it will always be fundamentally safer to travel on the surface even at 100 m.p.h. than it will to fly at great heights. As the author mentioned later in his

paper, man is not, and never will be, infallible; the occasional error will be made during design manufacture, or maintenance, and an accident will follow. The aeroplane always has the additional hazard of height to contend with: its potential energy is just as much a source of danger as its kinetic energy, and as the kinetic energy of the train. Is it not therefore unreasonable to expect the aeroplane ever to compete with surface transport on the score of safety?

In this country at least, rail travel is quite unnecessarily dangerous in fog. If one-tenth of the research effort which has been put into the development of aircraft Radar and other blind flying equipment during the past few years had been put into the development of automatic "in the cab" signalling systems on the railways, none of the train crashes in fog which have occurred year after year with such monotonous regularity need happen again. Surely the railways will not be allowed to stagnate technologically while the airlines progress; their accident figures cannot be expected to stand still while the aircraft figures decrease.

The high fatality rate quoted for private cars and taxis does not prevent many people from enjoying private motoring. The statistics for air transport fatalities will not prevent those who like flying from doing so, provided that the cost of flying (and of providing adequate life assurance cover) is not prohibitive. But all imaginative and thinking people will accept air transport much more readily when the fire menace has been subjugated, and when aircraft can be brought in to land at 50 m.p.h., instead of 100 m.p.h. Perhaps kerosene fuel will help to conquer the fire menace (assuming that rate of flame propagation is the important factor, and not quantity of fuel), while jet propulsion may indirectly improve the safety of landing by favouring low wing loadings for the advantages they confer in high altitude flight.

I am confident that ten times as many people would use the airlines if they did not fear the risk of being burned up after a relatively minor crash. However, it is an ill wind which blows nobody any good: it would indeed be hard on the taxpayer if John Citizen did start flying while his every flight cost his fellow taxpayers some £60!

Engine handling

I should like to know the author's reasons for stating that the constant cruising power technique is convenient. To whom is it convenient? With a reciprocating engine, why is it more convenient than flying at the lowest r.p.m. (permitted by operational limitations for weak mixture) which will give the necessary power, and varying the air speed as desired by boost adjustment?

Engines are not, and never have been, fitted with "power governors": there would be little point in providing such a device, and unless it were provided there would appear to be no conceivable operating convenience to be gained from flying at constant power. Such a technique results, as the author stated, in an air speed which increases with decreasing all-up weight, and is contrary to the fundamental economies of aerodynamics.

Some airlines tend to make a fetish of constant power operation, but I have yet to be shown just where its advantages lie. Surely there must be more in it than one libellous story I heard to the effect that, at constant power, "one could guarantee the engine fuel consumption rate and did not have to rely on the notoriously inaccurate tank contents gauges and fuel flowmeters." If there is no more in it than that, constant power operation hardly deserves further consideration, and it is a pity that it was assumed throughout the paper, with some penalty to the reciprocating engine because of failure to take full advantage of its operating flexibility.

I should like to congratulate Mr. Masefield and his staff on a very fine paper which must have involved a tremendous amount of work. It is good to see one in his position who is not afraid to admit that present fares are uneconomic with

existing aircraft, and that they would have to be trebled to enable even the more efficient airlines to pay their way. My own personal opinion is that fares should indeed be increased until we have aircraft and operators capable of making a profit at lower rates. It is reasonable to subsidise essential transport by air, but it is anti-social for the average taxpayer to have to subsidise holiday travel by air to the tune of a shilling per passenger mile, when he cannot himself afford to travel by air at all.

S. B. Bailey, A.F.R.Ae.S.

MR. MASEFIELD'S REPLY

I offer the following brief comments:—

(*a*) *Safety*

(*i*) I remain unshaken in my belief that the passenger mile is a better criterion than the passenger hour. The air traveller wants to cover a particular *distance* and not merely to spend a particular time in the air. In fact, the less time and more miles the better. The work done by an airline is measured in passenger miles; the same yardstick should be applied to its safety record—which is one aspect of its efficiency. Incidentally, there appears to be some confusion between miles and hours in Mr. Bailey's table of results.

(*ii*) Mr. Bailey appears to assume that air travel is inevitably more dangerous than surface travel. This does not follow. There is nothing fundamentally dangerous about flying at 500 m.p.h. so long as the aeroplane does not hit the ground or another body at high speed. And the air is still far less congested than the ground.

(*b*) *Engine handling*

As I explained in the lecture the "constant power" cruising procedure was selected from a number of alternatives as providing the most convenient régime for the purpose of making a general analysis. It offers a specific consumption which can be maintained at a low point on the consumption loop and, at the same time makes possible a reasonably fast operation. From a pilot's point of view it avoids one additional opportunity for maladjustment.

(*c*) *Fares*

I cannot accept the remedy of raising fares to make airlines pay. Any increase in fares would be accompanied by a rapid falling-off in traffic and air operators would find themselves worse off than ever. The converse may well be true. Reduce fares, increase traffic, spread costs and a gain in economy may well result.

P. G. Masefield, F.R.Ae.S.

REVIEWS

Jane's All The World's Aircraft 1948. Compiled and Edited by Leonard Bridgman. Sampson Low, Marston & Co. Ltd. London, 1948. £3 3s. 0d. net.

"You'll find it in Jane's."

So often has the reviewer heard that said, so often has he tested the truth of it, that he wonders sometimes that such a phrase has not been adopted by the publishers' as a slogan.

For find it in Jane's you will, if it is an aeroplane or an engine with the slightest pretension to being a member of the genus *Aeronautica.*

The only difficulty which may arise is knowing in which volume to look, for the compilation and editing and printing of this indispensable annual are the equivalent of putting many quarts into one pint pot. Inevitably year by year something has spilled over for the next annual.

But this year the editor and publishers have inaugurated a method of keeping the year's aircraft and engines in their proper twelve months by printing an inset supplement so that here is the Vickers-Armstrongs Viscount, which made its first flight on 18th July 1948, described in a massive volume which was published on 7th September 1948. Here also is the Nene-Viking with a note under the photograph that on 25th July 1948 it flew from London to Paris in 34 min. 7 sec. We draw special attention to the 7 sec. as showing the remarkable accuracy of timing between two of the major capitals of the World. Soon the Airways Corporations will have to put second hands on their clocks—we piously hope.

To review Jane's in detail would require more paper than is at present allowed.

This is the thirty-sixth *edition* of Jane, and she is more prepossessing than ever. Alas, however, she is as deceitful as all ladies are about their ages, for she was born in 1909 and next year she will be forty. But the reviewer will greet her next year with the ever-certain conviction that she will be as attractive as she was at—well, whatever age you like your love to be. Not to turn to Jane when in trouble about aircraft and aircraft engines is not to seek a source of information which is unique in aviation.

Essential Metallurgy for Engineers. A. C. Vivian, B.A.(Cantab), D.Sc.(London), F.I.M., Assoc.R.S.M., M.Inst.Met. Sir Isaac Pitman and Sons Ltd. 1948. 180 pp. 36 diagrams and illustrations. 12s. 6d. net.

This is the third edition of a work which was first published in 1942. It is to be hoped that this indicates that Dr. Vivian has gone a long way to attaining his original objective to supply engineers, technicians and students with a short account conveying complete understanding of essentials in modern control over the properties of metallic materials, and because of that there will be many more editions.

This is a book of great value to the structural engineer and all those concerned with the fabrication of metals and their alloys. On page 35, at the beginning of a chapter on The Mechanical Properties, the author says "this technology relating to the mechanical properties has employed as terms so many words which bear vague meanings, words which mean different things to different people according to their own particular experiences and feelings."

The truth of this is clearly too evident to all those who value the exact meaning of words, but it must be admitted the average engineer and many scientists have become increasingly determined to make words mean exactly what they want them to mean, as Humpty Dumpty decided.

This chapter on Mechanical Properties is one worthy of close attention, as are those chapters on the properties of straight carbon steels, alloy steels and, for aeronautical engineers, aluminium and magnesium-base alloys. Chapter XX is concerned with heat treatment for optimum properties.

This is a treatment of the strength of materials from an unusual and extremely helpful angle.

THE JOURNAL

OF THE

ROYAL AERONAUTICAL SOCIETY

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

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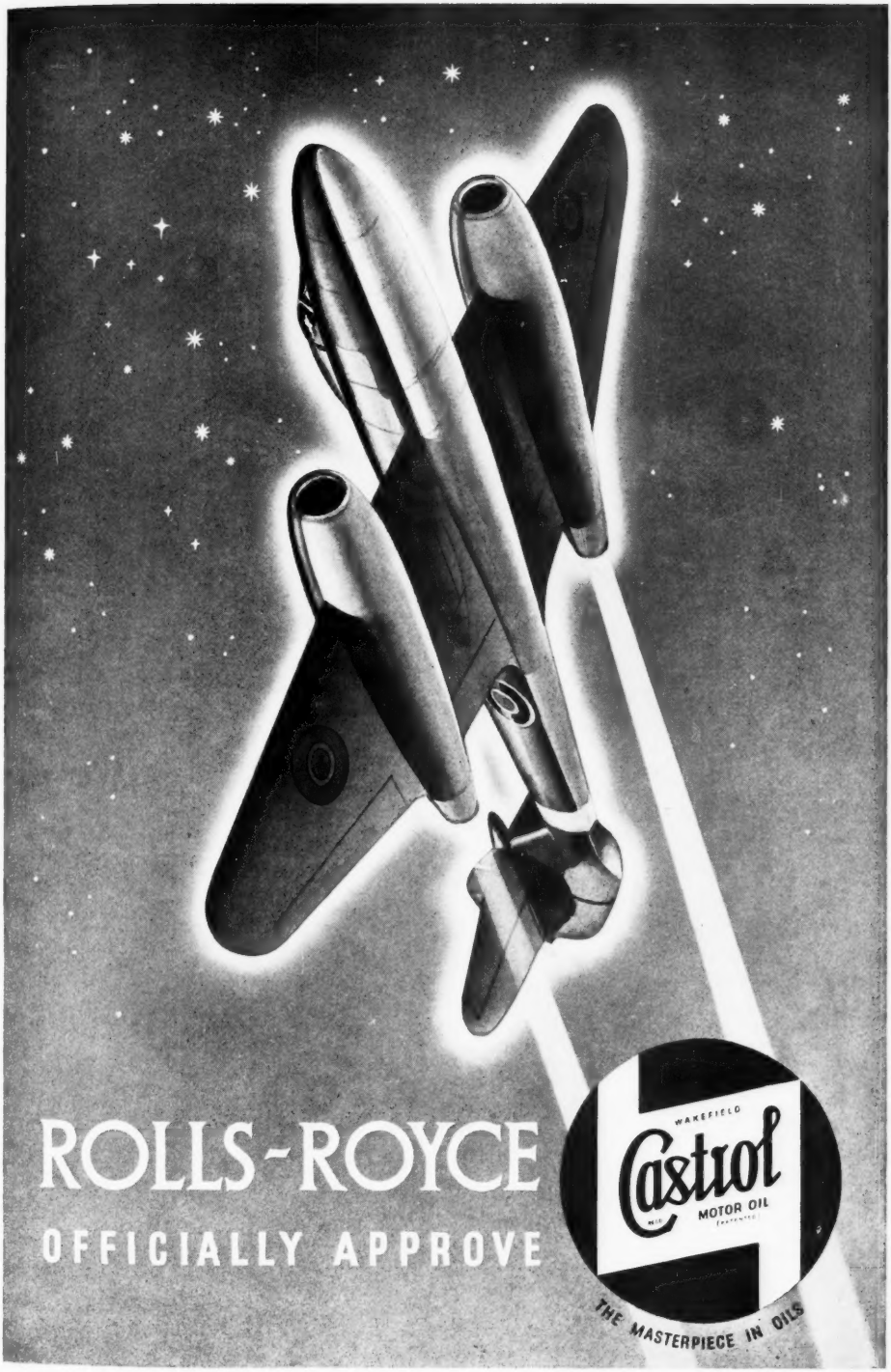
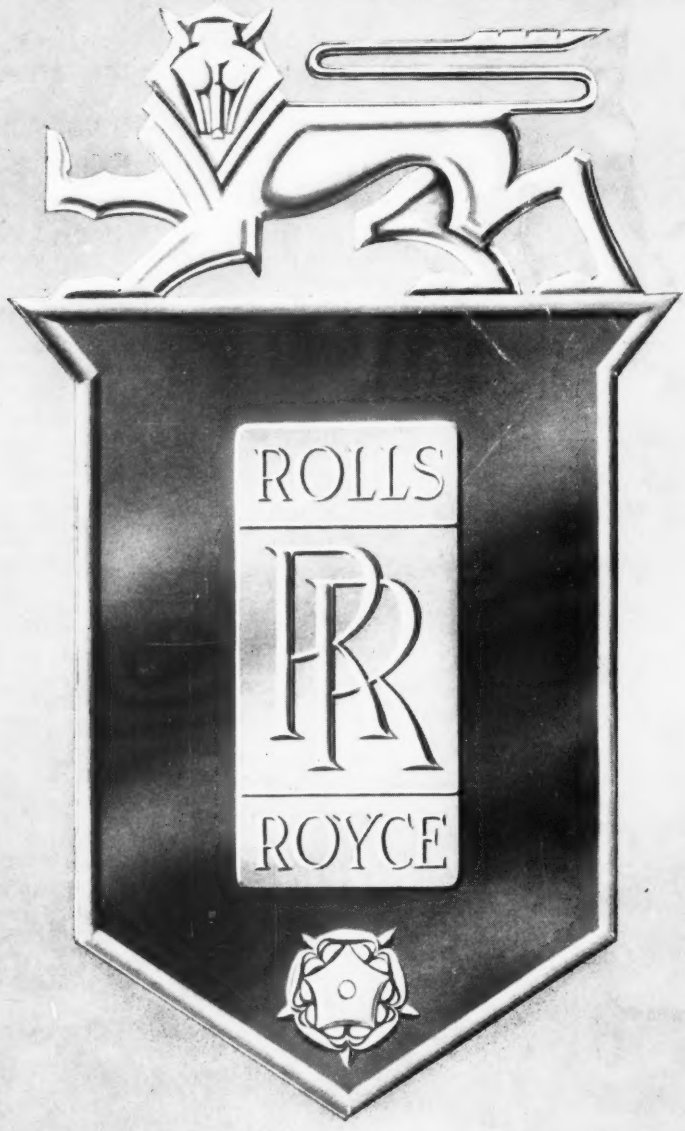


Printed by the Lewes Press (Wightman & Co. Ltd.), Friars Walk, Lewes, England, and Published by The Royal Aeronautical Society, 4 Hamilton Place, London, W.1, England.



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